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Technology and Oceanography

An Assessment of Federal Technologies for Oceanographic Research and Monitoring

Volume II—Working Papers on Fishery Research Technology

June 1981

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Washington, D. C. 20510

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This volume contains working papers written for OTA to assist in preparation of the report, TECHNOLOGY AND OCEANOGRAPHY.

The paper on fishery research technology reviews and appraises the existing Federal research programs on ocean fisheries and other living oceanic resources. Its major objectives are to evaluate how well the research technology and the programs provide the needed management information and how best to prepare for future demands on that technology and on the programs using it.

The appendix contains papers contributed to the Fisheries Research Technology Conference held April 21-24, 1980, in Seattle Washington.

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Preface

This volume contains working papers written for OTA to assist in preparation of the report, *Technology and Oceanography.* OTA does not endorse these papers. In several instances, the OTA report reaches somewhat different conclusions because of additional information that was obtained later. Nevertheless, they may prove valuable for readers needing more detailed or specialized information than could be accommodated in the final assessment report, and are being made available for such purposes.

i. b

Technology and Oceanography

An Assessment of Federal Technology
For Oceanographic Research and Data Collection

Volume II

Working Paper on Fishery Research Technology

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October 1980

i.c

EVALUATION OF
FISHERY RESEARCH TECHNOLOGY

i.d

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EVALUATION OF FISHERY RESEARCH TECHNOLOGY

PREFACE

This is a contribution to an assessment of ocean research technology that has been requested of the Office of Technology Assessment.

This report has been prepared under a contract between OTA and the College of Fisheries of the University of Washington in Seattle, Washington. Its preparation has been guided by a steering committee from the University of Washington consisting of

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EVALUATION OF FISHERY RESEARCH TECHNOLOGY

This evaluation reviews and appraises the existing Federal research programs on ocean fisheries and other living oceanic resources. Its major objectives are to evaluate how well the research technology and the programs provide the needed management information and how best to prepare for future demands on that technology and on the programs using it.

Because it is concerned with the ocean fisheries, this review will not examine the extensive freshwater fishery research technology, except that of the Great Lakes; or aquacultural research technology, except salmon ranching which utilizes the high seas. The review will cover the kinds of fishery research needed by all of our International Fishery Agreements and by all of our Regional Fishery Management Councils. Such research is concerned with describing the stocks, measuring the abundance of each, and forecasting the effects on them of fishing and of environmental changes; such research is commonly called stock assessment, though it includes several scientific disciplines.

The work on this review started with the preparation, by leading fishery scientists in the United States, of papers which are appended to this review. Most of these scientists, the steering committee, and staff members from the University of Washington then met in a workshop to review the papers and to discuss findings and recommendations. The workshop, the contributed papers, and numerous other references have provided the material for the summary which appears here.

RECOMMENDATIONS AND FINDINGS

1. Increase and improve the fishery research effort

a) The legal requirements for fishery management are now far more rigorous than the requirements under previous state or federal legislation.

--The requirements include those of the Fishery Conservation and Management Act (FCMA), the Marine Mammal Protection Act, the National Environmental Policy Act, the Endangered Species Act, the Coastal Zone Management Act, Executive Order 12044 on Improving Government Regulations, and various other administrative directives.

--The seven standards for the preparation of management plans under the FCMA (Sec. 301 [a]) each require scientific information on the stocks, and four of them require scientific information on economic and social aspects of the fisheries.

--The need for better social and economic information has been identified in other studies. Better information on the stocks is at least equally urgent.

--The preparation of management plans is a lengthy process and fishery scientists are involved throughout.

--The major obstacle to the optimum use of our marine fishery resources is no longer the lack of control over the fishing, but the effectiveness of the management and the information on which it is based.

b) The stocks sought by fisheries are many and diverse

--The stocks in the fishery conservation zone of the United States can probably sustain production of more than ten percent of the world's catches

--The stocks occur from the tropics to the Arctic, from the surface to the bottom, even in the bottom.

--The stocks include very large single species populations such as anchovy off California, very large multi-species populations such as New England ground fish, and small populations of high value such as bill fish and precious corals.

--Each stock is unique, and management requires knowledge of its life history, its abundance, and its reaction to fishing.

--About 500 stocks have been identified in the oceans and in the Great Lakes, although it is expected by NMFS that only about 70 of these will require management in the near future.

c) The increased demands of management have had a major impact on the research system.

--Many fishery scientists have been transferred from long-term research to short-term monitoring of stocks and delivery of the information to the Councils or other managers.

--In addition there has been a net reduction in total research personnel with transfers to non-research activities.

--The research information required by the managers needs to be timely, pertinent, and accompanied by the necessary economic and social information.

--The long-term research, essential for obtaining a better understanding of interspecies relationships and of the ocean climate's impact on the stocks, has been reduced.

--Much of the current monitoring program depends on the earlier investments in the long-range research, a trend that amounts to spending the accumulated research capital.

--The increasing demands of management on fishery research are additional to increasing demands to determine the impact of man-made environmental changes on the stocks.

d) More extensive application of existing fishery research theory, technology, and methods is the primary need.

--New remote sensing technology from aircraft or satellites has little direct application to stock assessment, but some important applications in measuring and understanding the ocean climate in which the fish live.

--The existing single species theory works satisfactorily for many species that are top predators or that are not major prey for other species.

--A great improvement in the accuracy of stock abundance forecasts is possible when they are projected up to one year after data are collected instead of two or more years, as is now required in the process of preparing management plans.

--The overall fishery research program should identify and emphasize both recurring monitoring and prediction and the long term research needed to improve understanding.

--Existing underwater acoustical instruments can greatly improve surveys of stock abundance.

e) Better understanding of interspecies conflicts and the impact of environmental factors on some major stocks is required.

--The New England, Gulf of Mexico, Gulf of Alaska, and Bering Sea ground fish stocks, which consist of several species each that are caught simultaneously by trawls, cannot be managed satisfactorily on the basis of single species theory.

--Major problems which cannot now be satisfactorily evaluated are the interaction of species especially the predator-prey relationship, the mixed catches, part of which may be non-target or non-saleable species, and the waste of young fish of valuable species.

--Total allowable catches derived by using single species theory for these complex stocks will exceed the sustainable catches of the stock as a whole.

--New theory and data suitable for estimating the maximum productivity of the fishing grounds while maintaining the populations of the more valuable species is required.

--Measures of the vitality of stocks such as the condition factors used in fresh water fishery research and oyster research should be developed and applied.

2. Plan better use of fishery research vessels

--Fishery research vessels may supply the primary data for stock assessment and must be used for the essential research on interspecies and environmental factors.

--Almost all fishery research vessels must be able to handle a variety of scientific gear as well as large fishing gear and its catches. Vessels lacking the ability to handle fishing gear are ill-suited for most fishery research.

--The federal fishery research vessel fleet now consists of ten vessels, two less than the fleet in 1970.

--The NOAA fishery research fleet capability is augmented about 50 percent by small program and charter vessels operated by NMFS, and about another 25 percent by foreign vessels operating in collaboration with the United States fishery research centers.

--About 90 percent of the research vessel time is used for stock assessment.

--With present costs (now averaging about $5,000/day for the NOAA vessels), effectiveness and efficiency are major considerations.

--University operated research vessels could augment the federal fleet more effectively with suitable long-range planning.

--Charters of especially equipped vessels for periods of several years may provide significant operational advantages and economies.

--The federal fishery research fleet has not operated as efficiently as it might have because of delays in adopting fully suitable equipment.

2. Research vessels (cont'd)

--Large, general purpose vessels have been used for limited purposes such as visual surveys of marine mammals when smaller vessels would have been adequate.

--Additional vessel capability is essential to provide for expansion of long term research and to replace the foreign research contribution which will probably be reduced.

--A review of the effectiveness of the NOAA fleet relative to other available vessels has not been made.

--Acoustical surveys of stock abundance from ships have by far the greatest range of uses among the remote sensing techniques. In some instances, they are the most effective method, but usually they must be augmented by trawl or other net sampling. Reliable and effective instruments and techniques are now available for many acoustical survey applications. However, accelerated research on hydroacoustic techniques is needed as well as more effective transfer of technical knowledge for broader fisheries applications.

--Small portable laboratories can be placed on board charter vessels to extend their usefulness.

3. Reorganize the fishery data system

--The most important data for stock assessment and fishery management must come from the fishery.

--Responsibility for gathering catch data is now divided in various ways between state and federal governments.

--Reliable data on the catch of each species, by each vessel, in each fishing area, and during each month, is basic. The number of days spent fishing in each area during each month is also essential.

--The incompleteness and inaccuracy of catch data are major issues in the management of many stocks.

--Supplementary examination of the catches by technicians who will collect size composition and age data is also essential in many fisheries. These technicians may work in port or as observers on board.

--Fishermen who have participated in successful management readily cooperate in supplying the needed data.

--Fishermen who suspect that the data may be used in order to collect taxes or restrain them unnecessarily are reluctant to supply the data.

--The analysis of these data must be prompt and must provide a better basis for forecasting.

--The presentation of these data must fill the needs of all of the users; fishermen, scientists, and managers.

--The analysis and publication of the catch statistics have been oriented primarily to the needs of the commercial users, not the managers.

4. Speed up management procedures to make use of better forecasts of stock abundance and optimum yield

--Implementation of domestic management under FCMA has been complex and is proceeding slowly.

--Many people involved in planning have had to become acquainted with new goals, objectives, standards, and procedures.

--Management of the foreign fishing proceeded quickly and smoothly.

--The new and rigorous management of domestic fisheries with the federal government involved was not expected by many fishermen. Some feel betrayed.

--The process of developing a fishery management plan requires extensive public participation. From 14 to 30 months are required after approval to proceed has been received from NOAA.

--Amendment of plans may require as much time as the development of the original plan.

--Estimates of expected catches and optimum yields can be far more accurate for one year in advance than for two to three years in advance.

--Implementation of plans has generally been most rapid in the Council areas where people were familiar with the previous international management, least rapid in the Council areas where only limited state management was previously in place.

--Greater use of operations research models by the Councils could improve the process.

--Greater use of framework plans that allow flexibility based on more reliable information without formal amendments could also improve the process.

5. Use fishery research to speed up fishery development

--Much of the product from the foreign fisheries off the United States is sold in highly competitive world-wide commodity markets.

--Methods of capture, handling, and processing at minimum cost and in ways that maintain top quality are essential.

--Many of the stocks in the conservation zone are unfamiliar to United States fishermen.

--The stock assessments can provide essential information to United States fishermen and processors on species, local abundance, size of fish, and seasonal abundance.

--The observers on foreign vessels can supply essential information on fishing and handling methods.

--Additional research is desirable on the requirements for maintaining product quality and safety with the unfamiliar species.

--Additional research on fishing gear is desirable in order to reduce the waste of unwanted species and sizes of fish from the mixed stocks.

6. Encourage further development of salmon ranching.

- --Salmon ranching, the only aquaculture that uses the high seas, now produces about 15 percent of the salmon harvested in the North Pacific and is growing rapidly.

- --Advanced technology is available and in use.

- --Public ranching predominates in North America, although there is great interest in private ranching.

- --Conflicts over "grazing rights," particularly in estuarine areas, are beginning and are expected to increase. Research is needed on the capacity of the salmon feeding grounds and how they can be most effectively utilized.

- --Private ranching will probably increase rapidly if the present political opposition subsides.

It should be noted that other mariculture activities may have similar problems and opportunities. The Gulf of Mexico penaeid shrimp is one example. A recommendation to encourage salmon ranching can only be realized if it compares favorably with other species, other regions, and other traditional fisheries.

7. Plan lengthy, complex research on marine mammals and endangered species

--The Marine Mammal Protection Act uses concepts, such as "health and stability of the marine ecosystem," "optimum carrying capacity of the environment," and "optimum sustainable population," that for most species cannot now be scientifically measured.

--Most of the research now under way is directed at developing the technology and programs needed to comply with the Act. Much work is needed before realistic programs can be planned.

--The many species of marine seals, porpoises, and whales each have diverse life histories and habitats.

--Almost all of the species live at least part of their lives outside of the fishery conservation zone of the United States.

--Reasonable abundance estimates can be obtained only for a few species that are harvested or that congregate in known places where they can be counted.

--Numerous special long-range ships (some of them ice-strengthened) and aircraft will be needed to census most of the high migratory species. Such censuses will be costly.

--The difficulties of obtaining scientific information on other endangered or threatened marine species such as turtles are similar.

--Damage to fisheries by coastal seals and sea lions is generating increasing conflict.

8. Plan research on Antarctic krill in collaboration with other nations

--Krill occupy an area about six times as large as the total fishing area in the United States fishery conservation zone.

--The sustainable annual yield is unknown, but the most generally accepted guesses indicate that it is about 100,000,000 metric tons.

--Much of the biology of the krill, especially its migratory and swarming behavior is too poorly known to design satisfactory assessment surveys.

--Fishing is now practical only on the "super swarms," not on the less dense aggregations.

--A catch by a hypothetical fleet of 1,000 large vessels might reasonably be estimated at 12,000,000 metric tons annually, and the impact of such a catch on the population as a whole might be too small to be measurable.

--Research to obtain fundamental biological data on the krill is now supported by several countries. The United States should join in this effort.

--Most of the trial fishing by other countries has been undertaken by idle long-range fishing vessels. The United States has no such idle vessels and no apparent commercial interest at this time.

--Major handling, processing, and marketing problems remain to be solved before large scale operation is possible. For example, the fluoride content of some samples has been far in excess of United States tolerance levels.

THE OCEAN FISHERIES SUBJECT TO RESEARCH AND MANAGEMENT

Since reaching worldwide accord on most aspects of the management of coastal marine resources (although a final convention has yet to be concluded), most of the coastal countries of the world have asserted authority over fisheries within a 200 mile wide exclusive economic zone bordering their coasts. This action was taken in the United States by means of Public Law 94-265, the Fishery Conservation and Management Act (FCMA) of 1976.

With this Act, the United States brought under its management at least ten percent of the conventional ocean fishery resources of the world. This is a surprising total because the United States commercial catches had been about level for the three preceding decades, and the United States had been importing about 60 percent of the edible fish it used. In 1970 the United States commercial catch was about 2.9 million metric tons (MMT) or about 4.9 percent of the world catch of 59.7 MMT.

Yet the total catch within about 200 miles of the U.S. coast in 1970 was about 7.4 MMT, of which about 58 percent was caught by foreign vessels, 34 percent by U.S. commercial, and 8 percent by U.S. recreational fishermen (U.S. Dept. of Commerce, 1974). These proportions have changed somewhat since 1970. The United States commercial catch in 1978 was about 3.5 MMT (U.S. Dept. of Commerce, 1980), and the foreign catch was about 1.7 MMT (and no survey was made of marine recreational fishing). These changes reflect both the restraints placed on the foreign fishing and the increased opportunities for United States fishermen to seek stocks which had been almost exclusively fished by foreigners.

The larger catches off the coast of the United States by both foreign and domestic vessels caused a concern for the stocks similar to that on most of the fishing grounds of the world. During the '50s and '60s, the world's catch of fish tripled, and during the '70s the trend nearly leveled off. Most of the conventional resources seemed to be producing close to their sustainable limits.

In this situation, the FCMA has a worldwide significance. The Act is generally consistent with provisions of the protracted international discussions on the principles of worldwide fishery management. It establishes United States authority over the resources and the fishing in a Fishery Conservation Zone. But, unlike many of the earlier attempts by coastal countries to claim extension of fishery jurisdiction, the FCMA is not designed to establish exclusive use. It makes specific provision to allow foreign fishing when domestic fishermen will not take the entire optimum yield (Sec. 201 [d]).

TRENDS IN FISHERY MANAGEMENT

The current concern about fishery research arises primarily from the demand for better information on which to base the management of the fishery. And a demand for better management has arisen from research findings that the previous management has not been as good as it might be. Thus, we have had a cycle of management failures stimulating research, and the research findings stimulating better management.

Early objectives

Prior to World War II, the objectives of fishery management were stated as preservation or conservation without an explicit definition of either. The methods were based on the popular concepts of protecting the young and breeding animals; of preventing waste, for example by taking animals in poor condition; and of preventing excess efficiency in the capture of the animals. When the yield from the resources declined, widespread efforts (mostly unsuccessful) were made to enhance the resources by stocking young from hatcheries. Attention, of course, was focused on the freshwater and inshore marine resources, because these seemed to be in the greatest danger, and because the view still prevailed that the resources of the high seas were inexhaustible.

Many regulations had nothing to do with conservation, but were designed to allocate the catches among fishermen or to assist buyers and processors in marketing. As it became obvious that stocks could be overfished (for example in the case of the Pacific salmon), the regulations were designed to restrain the fishermen with respect to his gear and equipment, his fishing time and location, and his total catch. Fishing was prohibited in places and at times when fish were in poor condition for market.

Maximum Sustainable Yield and its modifications

Following the acceptance of the pioneering research on the dynamics of fish populations during the '30s, the concept of maximum sustainable yield began to be recognized as an objective of fishery management. This concept had been implicit, but not stated, in the Halibut Conventions of 1923, 1930, and 1937 (Bell, 1967). But the advances in understanding of fish populations and the experience gained in the Halibut Conventions and the Sockeye Salmon Convention of 1930, both of which placed strong emphasis on research, led to the identification of MSY as an explicit objective in the Conventions that followed World War II. Now all of the approximately 20 bilateral and multilateral fishery agreements of the United States identify MSY or a modification, such as optimum yield (OY), as the objective.

The modifications have arisen for a variety of ecological, economic, and other social reasons. The ecological reasons relate to the concept, not the objective, of MSY as a long-term average of the relationship between the amount of fishing effort and the expected yield. In the usual fish population, which is subject to highly variable survival of its young from year to year, MSY is not a suitable objective for each year's catches. The OY will change annually to allow greater catches from the abundant year classes and more protection for the scarce year classes.

Further, the theory of a MSY has been developed for single species populations and has been found in practice to apply best to the populations of only the dominant predators in mixed fish stocks. In such stocks, some species are eaten by others, usually when young, or crowded by others. These factors of predation or competition may influence the abundance of parts of the stocks more than the fishing. In such stocks, a total allowable catch (TAC) set on the estimate of MSY for each species will exceed the TAC for the stock as a whole. And regulations to limit the catch of each species may not be feasible.

The economic and other social modifications arise from the need for the management to be fair to all participants who may include many kinds of commercial, recreational, and subsistence fishermen. Each kind will have a different mode of operation and a different ability to catch each species. Each kind will be affected differently by each regulation. The problem of a fair allocation among all fishermen has been the major consideration in the development of regulations.

A major step toward international agreement on the objective of fishery management appeared in the 1958 Convention on Fishing and Conservation of the Living Resources of the High Seas. Conservation of the living resources of the high seas was defined as "the aggregate of the measures rendering possible the optimum sustainable yield from those resources so as to secure a maximum supply of food and other marine products."

Notwithstanding the widespread adoption of MSY or OY in the International Fishery Conventions, there has been little explicit recognition of these concepts in the domestic fishery regulation of the United States. This lack of recognition appears to have occurred for a variety of reasons. The fishery regulations of several states have been concerned predominantly with recreational fishing, and there are about 350 recreational fishermen in the United States for each commercial fisherman. The recreational fishermen have rarely accepted (or even been asked to accept) the concept of MSY because their catches are only part of a valued outdoor experience. In all of the states, freshwater and inshore coastal fisheries have had a long history of regulation which has developed from the older concepts and which is slow to change. All of the states lack complete control of the fishing on the stocks that migrate across state borders. Furthermore, few of the coastal states have research data on their numerous offshore stocks sufficient to support management for OY.

The inclusion of a yield objective in the Fishery Conservation and Management Act of 1976 was a major extension of the principle in a conceptual sense to most of the state agencies and to the fishermen concerned. The concept has been more readily accepted by those experienced with the international treaties in which it is embodied and has been found to work. Others have found themselves dealing with new concepts, new kinds of data, and new methods of arriving at decisions.

In addition to the complications of having a yield objective, the definition of optimum yield has been difficult to arrive at (Bevan, 1980). The FCMA (Sec. 3 [18]) defines optimum yield as "the amount of fish (A) which will provide the greatest overall benefit to the Nation with particular reference to food production and recreational opportunities; and (B) which is prescribed as such on the basis of the maximum sustained yield for such fishery as modified by any relevant economic, social, or ecological factor." These modifying factors are quantifiable only with difficulty, if at all.

Goals other than Maximum Sustainable or Optimum Yield

The goals of MSY and its modification OY are gradually being defined by the scientists and the people affected by them, but even less scientifically definable are the goals of other Acts. The Marine Mammal Protection Act of 1972 declares that stocks of marine mammals should not fall below a level "which will result in the maximum productivity of the population or the species, keeping in mind the optimum carrying capacity of the habitat and the health of the ecosystem of which they form a constituent element." Elsewhere the Act provides "that it should be the goal to obtain an optimum sustainable population keeping in mind the optimum carrying capacity of the environment."

In addition to the difficulty of defining these goals scientifically, it is also difficult to obtain most kinds of scientific information for these species. If species are totally protected from harvest, as are most of the marine mammals affected by this act, they can be studied only by scientific expeditions, not by observing their capture for some other purpose.

Complexity of U.S. fishery management

The task of managing the domestic ocean fisheries is a very large one. A review of the status of the United States fisheries during the middle '60s (U.S. Dept. of Interior, 1969) listed the stocks of coastal fish in five marine regions plus the Great Lakes and Hawaii. They totalled 284, of which 49 were judged to be fully utilized or overfished. Of course, most of these 49 stocks were the more valuable and sought-after stocks.

This report also described the fishing area adjacent to the United States as the continental shelf and the upper part of the continental slope out to a depth of 300 fathoms. This area, almost all of which is within the 200 mile zone, amounts to about 800,000 square nautical miles or an equivalent of about 30 percent of the land area of the United States. The report projected a minimum annual production potential of 19,000,000 tons which then was about five or six times as great as the United States catches by both commercial and recreational fishermen. As was pointed out earlier, the resources of this area probably comprise at least ten percent of the total conventional fishery resources of the world.

Another review of the United States ocean fishery resources and their management was undertaken in the early '70s (U.S. Dept. of Commerce, 1974). This review included a summary of the total catches and the management status of the 31 most important species or species groups, most of which comprised many stocks (Table 1). The judgmental report on the status of management of these species groups revealed that many of them, even some that were considered to be overfished, were being

Table 1:
SOME BASIC DATA ON THE EXTENT OF FISHERY MANAGEMENT IN 1970

Species Group	Landings, 1970 [1/] Millions of Pounds	Status of Management Outside Three Miles by States and International Agreement
Pollock	5,649	None
Menhaden	1,814	None for OY. Various restraints for alleged protection of other species.
Herrings	1,786	Complex state quota. Gear, season, and state restrictions on three stocks. International quota on one stock.
Flounders	820	International quota, mesh size for yellowtail. State restriction on a few of the other stocks.
Oysters	724	Fished entirely within three miles.
Ocean Perch and Rockfish	603	None except an international agreement to close some areas off Oregon and Washington.
Tunas and Bonitos	510	Most tunas regulated for OY by international agreements. No management of bonitos.
Hakes	487	None except two international agreements to reduce low gear conflict.
Clams	475	None
Salmon	448	Most stocks migrate outside three miles, but U.S. net fishing is prohibited there. Inside three miles, very complex state regulations on size, season, bag limit, quota, gear. Large-scale enhancement through aquaculture.
Shrimps	473	No overall management. About half caught within three miles. Many complex state regulations.
Crabs	365	Complex sex, seasonal, size, gear, and quota restraints on some stocks by states and international agreement.
Mackerels	301	Complex state regulations

[1/] Includes U.S. commercial, foreign commercial, and recreational catches.

Table 1:
THE EXTENT OF FISHERY MANAGEMENT (continued)

Species	Landings, 1970	Status of Management Outside Three Miles
Croakers, Drum, Spit	238	Most catches made inside three miles. Some state regulations.
Cod	232	Mesh regulations by international agreement in Atlantic.
Anchovy	192	Quota restraints far below level of OY.
Sea Trouts	166	None
Whiting (Atlantic)	146	International closure of area and season. Effect not evaluated.
Bluefish	128	Some state limits on size.
Scallops	126	None
Striped Bass	94	Stocks fished almost entirely within three miles.
Halibut	79	Regulated for OY by international agreement.
Catfish (Marine)	73	Stocks fished almost entirely within three miles.
Scup	67	None except a seasonal closure off mid-Atlantic by international agreement.
Sablefish	56	None
Snappers	51	None
Groupers	49	None
Jack Mackerel	48	None
Lobsters	44	Various state regulations of the portions of American and spiny lobster catches beyond three miles.
Haddock	43	Mesh, seasonal, area, quota restraints by international agreement.
Mullet	34	State limits for season and size
	16,281	

Source: Condensed from U.S. Department of Commerce, NOAA, NMFS. 1974. The United States marine fishery resource. 379p; and OTA. 1977. Establishing a 200 mile fisheries zone. 132p.

managed inadequately, if at all. Some states had no effective regulation of outside ocean fisheries. Among those that were being managed, few, except those subject to an international agreement, were being managed with an objective of MSY or OY. Such an objective was not required in domestic fishery management.

Still another review appeared just after the FCMA was passed (U.S. Dept. of Commerce, 1976). This report listed species which were thought to be overfished or in danger of being overfished, of which some stocks were overfished. Those endangered primarily by foreign fishing totaled 15; by a combination of foreign and domestic fishing, 12; and by domestic fishing alone, 7 (Table 2).

Under FCMA, which became effective March 1, 1977, a clear federal authority was established over a fishery conservation zone defined as the area between the outer limit of state authority (usually three miles) and 200 miles from the coast (Sec. 104). Provision had been made for bringing the foreign fishing under control as of this date, and it was done (Comptroller General, 1977). Such fishing was allowed only under permit (Sec. 204 [a]) and in accordance with preliminary management plans. Systems were soon established for placing observers on board the foreign vessels, for boarding them occasionally at sea, and for obtaining frequent radio reports of their catches.

Such quick action was possible because each nation which wanted to send vessels to fish in the fishery conservation zone had to be party with the United States to a governing international fishery agreement (Sec. 201 [c]), and because most of the foreign captains had become familiar with the concepts and methods of the similar fishery management under the preceding international fishery agreements. But another important factor was the extensive base of information that had been developed through research by United States and collaborating foreign institutions. This base permitted development of plans in compliance with the National Standards for Fishery Conservation and Management (Sec. 301) and the Contents of Fishery Management Plans (Sec. 303). The plans were quickly accepted because there was little opportunity for challenge by foreign fishermen, and, since the plans generally required a sharp reduction in foreign fishing, they were not challenged by domestic fishermen.

The preparation and acceptance of plans for domestic fishery management has been far slower and more complex. The domestic fishermen who were sharing

Table 2:

STATUS OF SELECTED FINFISH AND SHELLFISH STOCKS, July 1975

Finfish species over fished (excluding tunas and billfish)

--Primarily by foreign fishing:

Atlantic mackerel	Northwest Atlantic and Mid-Atlantic Bight Southeast U.S. coast
Haddock	Northwest Atlantic and Mid-Atlantic Bight
Atlantic sea herring	Northwest Atlantic and Mid Atlantic Bight
Yellowtail flounder	Northwest Atlantic and Mid-Atlantic Bight
Pacific halibut	Gulf of Alaska, East Bering Sea
Pacific ocean perch	Northwest U.S. coast, Gulf of Alaska, East Bering Sea
Alaska pollock	East Bering Sea
Sablefish (black cod)	East Bering Sea
Pacific sea herring	East Bering Sea
Pacific hake	Southwest U.S. coast, Northwest U.S. coast

--By foreign and U.S. fishing:

Summer flounder	Northwest Atlantic and Mid-Atlantic Bight
Alewife (a river herring)	Northwest Atlantic and Mid-Atlantic Bight
Blueback herring (a river herring)	Northwest Atlantic and Mid-Atlantic Bight
Atlantic salmon	Northwest Atlantic and Mid-Atlantic Bight
Total finfish biomass	Northwest Atlantic and Mid-Atlantic Bight

--Primarily by U.S. fishing:

Atlantic menhaden	Northwest Atlantic and Mid-Atlantic Bight, Southeast U.S. coast
Pacific barracuda	Southwest U.S. coast
Pacific mackerel	Southwest U.S. coast
Pacific sardine	Southwest U.S. coast

Finfish species in danger of being overfished, or of which some stocks are overfished

--Primarily by foreign fishing:

Red hake	Northwest Atlantic and Mid-Atlantic Bight
Silver hake	Northwest Atlantic and Mid-Atlantic Bight
Rockfishes (excluding Pacific Ocean perch)	Northwest U.S. coast, Gulf of Alaska, East Bering Sea

Table 2:

STATUS OF SELECTED FINFISH AND SHELLFISH STOCKS (continued)

--By foreign and U.S. fishing:	
American dab	Northwest Atlantic and Mid-Atlantic Bight
Cod	Northwest Atlantic and Mid-Atlantic Bight
Grey sole	Northwest Atlantic and Mid-Atlantic Bight
Scup or porgy	Northwest Atlantic and Mid-Atlantic Bight
Winter flounder	Northwest Atlantic and Mid-Atlantic Bight
Pacific salmons	Northwest U.S. coast, Gulf of Alaska, East Bering Sea
--Primarily by U.S. fishing:	
Menhaden	Gulf of Mexico
Shellfish species overfished	
--Primarily by foreign fishing:	
Shrimps	East Bering Sea
--By foreign and U.S. fishing:	
Sea scallop	Northwest Atlantic and Mid-Atlantic Bight
--Primarily by U.S. fishing:	
Pandalid shrimps	Northwest Atlantic
Shellfish species in danger of being overfished, or of which some stocks are overfished	
--Primarily by U.S. fishing:	
American lobster	Northwest Atlantic and Mid-Atlantic Bight

Source: U.S. Department of Commerce, 1976 stocks with the foreign fishermen expected a bonanza after the foreign fishing was reduced, apparently forgetting that their fishing had been a factor in the overfishing of some of the stocks. Quite naturally they resisted restraints. But most of the challenges to management proposals have come with respect to the stocks on which there is now little, if any, foreign fishing. The rigorous requirements of the FCMA had not been followed by the several states in their earlier management and have been unfamiliar to the Council members and to the fishing industry being managed (Comptroller General, 1979).

Not the least of the problems of developing the management plans under FCMA is the requirement for information based on research. A research base is required to demonstrate compliance with all seven items in the National Standards (Sec. 301 [a]) and with almost all of the items in Contents of Fishery Management Plans (Sec. 303 [a] and [b]). Special demands on the research base occur when the Councils consider all of the alternative regulations by quota, gear, area, season, and size of fish. A further demand on the research base is made during the preparation of the Environmental Impact Statement required for each Fishery Management Plan under the National Environmental Policy Act of 1973.

The accomplishment of the management under FCMA through the end of 1979 is indicated by Table 3. Of the 76 plans that had been identified or were in some stage of development, only ten had been implemented, and of these, five were plans that involved foreign fishing. Perhaps it should be noted that twelve of the 76 plans that had been identified involved stocks that were not included in the list of 284 stocks prepared during the middle '60s (U.S. Dept. of Interior, 1969). New fisheries had developed during the intervening years to the point at which management appeared necessary. Furthermore, each plan that has been implemented has been subject to annual review and revision, a process that will probably continue.

Future fishery management

The FCMA is obviously the beginning of major changes in fishery management in the United States. Foreign fishing has been brought under control and greatly reduced, but the domestic fishery management is as yet little changed.

The next step will obviously be to bring under management the many stocks identified as needing management, but for which plans have not yet been completed. This step will be difficult to accomplish while keeping the already implemented

Table 3:
STATUS OF MANAGEMENT PLANS --- December, 1979

Council	Number Identified as being developed	Number Implemented	Number with foreign fishing involved
New England	10	2	2
Mid-Atlantic	13	2	1
South Atlantic	7	0	--
Caribbean	6	0	--
Gulf of Mexico	11	1	0
Pacific	10	2	0
North Pacific	14	3	2
Western Pacific	5	0	--
TOTALS	76	10	5

Source: Department of Commerce, NOAA, NMFS, Council Memorandum, Volume 3, no. 12, December 1979.

plans under annual review and possible amendment. In addition, it is likely that some stocks not yet identified as needing management will at some time come under heavier fishing and will then be in need of management.

Along with this extension of the management will be a continuing redefinition of the biological and social objectives of optimum yield. The biological and social objectives will surely be refined as a better understanding is gained of the complex multispecies problems and as better predictability of the various alternatives is developed. The social objectives will probably be extended to consideration of the merits of stable versus fluctuating yields and to fairer methods of allocation among users.

Consideration will need to be given to bringing some stocks quickly under management when they are obviously reduced in abundance but when all of the factors responsible are not understood. The management approach will probably need to be conservative and experimental.

In addition to these longer range developments, improvements will be made in the current implementation of FCMA as has been recommended already by GAO. Their recommendations included collection of better data on biological, social, and economic problems; improving the coordination with the states with respect to regulations and enforcement; improving public participation and understanding; and speeding up the planning process.

TRENDS IN MARINE FISHERY RESEARCH

Fishery research is scientific investigation applied to the problems of managing fisheries, of managing our use of the aquatic environment in which the fish live, or of growing fish as a domesticated crop. Such research includes biological, physical, chemical, oceanographic, economic, and other studies as may be necessary.

Such a broad concept of fisheries research has not always been current. Early fishery research, prior to its rapid increase in application, was one of the natural history sciences concerned largely with description of the aquatic environment. This emphasis persisted until the 1950s at the numerous public and private biological stations along our coasts.

Emergence of resource assessment

The impetus for change started with the successful Halibut Conventions of

1923, 1930, and 1937 and the Sockeye Salmon Convention of 1930, all of which mandated scientific research as a basis for Commission decisions. This pattern of reliance on research became the model for the structure of each of the numerous international fishery conventions negotiated during the '50s and '60s. The research base has strengthened all of these conventions and has been supported increasingly as the world's fishing capability tripled during the '50s and '60s. Now, with the capability of overfishing almost any valuable and unmanaged fishery resource, the demand for research to guide the management decisions continues to grow.

The early success of management based on MSY or OY, and many recent ones, too, have been in part fortuitous. They have occurred with fish stocks that were top predators in their ecological niches or with stocks that did not have a strong interaction with other stocks. In such cases, results support the basic assumptions that fishing is the major variable in the mortality and that the relationship between the size of the stock and the amount of fishing is satisfactorily predictable.

With stocks that are major prey species, the fishery may cause only a minor part of the mortality and have an unpredictable relationship to the size of the stock. Similarly, if the stock is short-lived and subject to highly variable survival because of environmental changes, the effect of fishing on the stock cannot now be predicted.

Some of these stocks are parts of multispecies complexes, such as the New England or Gulf of Alaska bottomfish. Others may be a dominant stock such as the anchovy off California which apparently has varied in its abundance for natural reasons which are not known.

In either case, the stocks are parts of a complex production system that is not adequately understood. More wide-ranging, ecological research is necessary before a monitoring and prediction system can be satisfactory.

Considerable experience has been gained, however, with large multispecies systems. In the Great Lakes, for example, the overall production of each lake has remained at roughly the same level for many years, but the species mix has changed dramatically. The valuable species that were first sought have almost disappeared to be replaced by much less valuable species. The present management is attempting to reverse this trend.

Across the Atlantic in the North Sea the overall production has been much less variable than the production of some of the major stocks such as herring. But the overall production, which was relatively stable for years, increased dramatically in the middle '60s to a new level which is still being maintained. The increase had not been predicted, nor has it been satisfactorily explained.

FISHERY STOCK ASSESSMENT AND ITS TECHNOLOGY

Fishery stock assessment includes studies which describe the stocks, assess their abundance, and measure the impact of the fishery on them.

Methods of stock assessment

A stock is defined in FCMA as "a species, subspecies, geographic grouping, or other category of fish capable of management as a unit." Ideally, it is an intermingling group of one species, but many fisheries catch mixed species, and it is the activity of a fishery that must be managed.

After defining a stock, it must be described with respect to where it lives; where it migrates; if and how it schools; when, where, and how it spawns; how fast it grows; how old it gets; what it eats and what eats it; and perhaps even other aspects of its biology. Such information provides the basic understanding on which the management should be based, and without which satisfactory estimates of abundance cannot be made.

The abundance of a stock is its size in terms, actual or relative, of the numbers and weight of the individuals in it. Abundance is the fundamental quantity required periodically for management decisions. It may be determined as a relative value by obtaining the catch-per-unit-of-effort of the fishing fleet, or as an actual value by controlled sampling with gear of known selectivity. The latter procedure requires a vessel assigned to the sampling--not a vessel engaged in commercial fishing.

Given the abundance and the amount of fishing effort over a period of time, it becomes possible to estimate the mortality rate; and given also the growth rate, it is possible to estimate the effects of fishing on the stock and the level of sustainable yield.

All of the above sounds simple, but in practice it is not. Most fish migrate seasonally between spawning and feeding grounds. Many behave differently with different hours or seasons and change in their availability to fishing or sampling gear. All change in their availability to gear as they grow from larvae through the juvenile stages to adults, because no fishing gear is completely non-selective. Any mesh in a net will let small animals go through, and no net can be pulled fast enough to capture all of the swiftest and largest fish. No sample can be completely unbiased.

A consequence of the complexity of these variables is that stock assessment depends not only on rigorous methods, but also on experience and judgment. And it follows that the credibility of the recommendations based on stock assessment must stand the test of time.

The validity of the stock assessment depends, also, of course, upon the quality and quantity of basic data. The most important source is the fishery itself. It is vital to the whole management process to have information on the catch and fishing effort by time, species, size of fish, area, and gear. Such information provides not only an assessment of the capacity of the stock to sustain the catches, but also an assessment of the capability of the fleet to make the catches.

An alternate and, in some respects, a superior source of information is survey by research vessels, which can provide unique information about eggs, larvae, and pre-recruit sizes not sought by the fishery through the use of special gear and by operation in areas not fished by the fleet. It can also provide less biased samples of abundance and a greater opportunity for biological studies of the catch. Such surveys are expensive, however, and they cannot provide the assessment of the capacity of the fleet to make the catches.

A method of capture is necessary for the assessment of the abundance of most fish, but some fish can be observed and counted directly. Menhaden that school near the surface can be spotted from aircraft. Salmon can be counted as they ascend the streams. The air-breathing animals, such as whales and turtles, can also be counted directly from vessels or aircraft, although those that live far from land pose some difficult logistic problems.

An auxiliary method of assessment rapidly increasing in effectiveness and use is acoustical remote sensing. Instruments with satisfactory range, sensitivity, and stability are now available to detect fish up to about one kilometer from a ship. Such instruments provide an extremely valuable method of extending and speeding vessel surveys, especially those of fish that live midway between surface and bottom. The instruments cannot, however, identify fish species except in certain cases, nor can they assess the abundance of fish very close to the bottom or to the surface.

Fish, of course, live where the environment suits them. Each stock will live in or with suitable depth, bottom type, temperature, food animals, salinity, oxygen, and opportunity to escape its predators. But the preferred or tolerated environment changes with the time of day, season, spawning time, and size of the individual.

Especially critical is the environment of the larvae after hatching from the egg. The larvae of most of the commercial species are freely drifting animals four to seven mm long (about 1/4 inch) that live a hazardous life. Each one may require food of the right kind and size every few minutes and, if it gets food, its weight may double in a week. It is also extremely vulnerable to predation and may have a more than one-in-ten chance of dying each day. Such larvae are produced by the hundreds of thousands or millions by each female, so the high mortality rate is normal; but measuring deviations from the normal that will eventually change the size of the stock is exceedingly difficult.

Observations of surface conditions such as temperature, currents, salinity, or chlorophyll (which may indicate productivity) have been useful occasionally to locate surface fish, especially certain tunas that follow productive ocean currents or temperature boundaries. But most fish live below the surface where conditions are different and not predictable from surface conditions. Further, they are affected not only by the conditions of the moment, but by the combinations of conditions during weeks or months. Consequently, the discovery of environmental measurements that can be used to predict the abundance of fish (as contrasted to the location) has been difficult. In only a few cases has it been possible to find, between environment and survival, a cause-and-effect relationship that is a useful basis for prediction of abundance. An example of such a relationship is the high mortality of larval menhaden when currents carry them offshore instead of inshore toward the estuaries where they must live as juveniles.

In addition to the natural conditions in the oceans, man-made changes are occurring, especially in the estuaries. Toxic wastes, overloads of organic materials, and major physical changes have disrupted the ecology of many estuaries and are beginning to produce measurable changes in the ecology of the open ocean.

Study of the impact of such changes on the stocks is a large and increasingly urgent assignment of fishery researchers.

The usefulness of satellite or aircraft observations of ocean surface conditions for the purpose of predicting the abundance of a stock has yet to be demonstrated, but such observations are being used by many researchers as part of their research on the ocean. They are especially important for providing nearly simultaneous information on the surface conditions over the entire range of a stock.

Reliability of predictions

Predicting the abundance of fish is, in some basic principles, like predicting the weather, or elections, or other events. The reliability of the prediction is a function of the time between the collection of data and the predicted event after the collection of data. If the time is short and the event consistent, the prediction can be good.

If, for example, a year class of fish has been recruited (i.e. become available) to the fishery and its abundance is measured, a prediction of its abundance the following year can be highly reliable, more so than two or more years later. To use a specific example, it has been pointed out on the basis of 20 years data from the fisheries that the catch of Georges Bank haddock with a given amount of fishing can be predicted one year in advance within 16 percent 19 years out of 20 (Royce and Schuck, 1954).

It happens that the natural mortality rates of haddock and most other species of fish during the years following recruitment are reasonably consistent. But during the egg and larval stages the survival of most ocean fish is very uncertain. The variability is such that a prediction of the abundance of a year class based on the abundance of the parents is nearly worthless.

The use of the spawner-recruit relationship either directly or implicitly for the calculation of MSY has led to confusion in its interpretation. The relationship is a long-term average, and it indicates the abundance of adults that should be maintained on the average, not necessarily every year.

The basic data for predicting catches must include an estimate of the abundance of the stock and the capability of the fishery to catch it. Estimates of both can be obtained from the fishery data and can be quite accurate for the older age groups in the catches. But the fishery has no prior experience with the age group just being recruited to the fishery, and this group may be a large fraction of the stock. A prediction of its abundance must be made from a known relationship to measurable environmental factors, from the catches of special nets used by research vessels, or from the spawner-recruit relationship which, as noted above, is highly variable.

Future fishery research

Stock assessment research is driven and shaped by the needs of the fishery managers. The major need, as noted above, is for better information on a large number of stocks which have not been managed as rigorously as required under FCMA. This need is a continuing one for each stock, since it is subject to annual review for possible amendment of the management. It is also an extraordinarily complex need because each stock varies in its location and habits, and the fishery of each stock varies from those of the others.

Most of these needs will be met by extending the existing theory and technology to hitherto unmanaged stocks as they are brought under management and by refining those methods. It will be a relatively routine research directed at monitoring and prediction.

But the familiar methods have been found wanting when applied to some important bottomfish stocks, which are complex mixtures of species, and to some very large herring and anchovy stocks, which have unexpectedly collapsed. In these instances, a better understanding of the non-fishery factors is essential and can be gained by research aimed at a better understanding of the ecological production process. Conducted on a scale adequate to measure the environmental and the interspecies relationships, such research should be expected to be non-routine, expensive, and lengthy.

FISHERY RESEARCH VESSELS

Fishery research vessels for stock assessment must be able to handle fishing gear and the fish that are caught, in addition to oceanographic instruments. Handling large fishing gear such as trawls and seines requires major structural and power arrangements. Handling the catch requires deck space for sorting it, laboratory space for studying it, and storage space if it is not to be wasted. Handling the smaller fishing gear such as gill nets and long lines requires lesser structural modifications, but decks must be close to the water, and space must be provided for handling, studying, and storing the catch. The NOAA fishery research fleet of ten vessels (with the recent addition of the Chapman) is operated for the National Marine Fisheries Service by the Office of Fleet Operations of the National Ocean Survey of NOAA (Wolf, 1980). The budget for the operation of the fishery vessels for FY 79 was about $9,600,000, or about one-fourth of the NOAA fleet budget. This sum provides about 2,000 days of sea time. In addition, NMFS budgets about $2,000,000 for vessel charter and about $250,000 for operation of small vessels operated by NMFS. About 90 percent of the ship time supports the resource assessment program.

Foreign fishery research vessels have recently assisted with stock assessment surveys and have added about 400 sea days to the research vessel capability. This activity started under the International Fishery Agreements and has been conducted in full collaboration with NMFS Fishery Centers. It has continued under FCMA because it is now a consideration in the determination of catch allocations among the foreign nations that want to fish (Sec. 201 [e] [2]). Such nations may be reluctant to contribute as their catches are reduced.

CURRENT STOCK ASSESSMENT OPERATIONS

Budgets

Out of a total research budget of about $44,000,000 in FY 79, the NMFS identified about $32,000,000 with stock assessment activities (NMFS, 1980). To this was added about $9,000,000 for the operation of the fishery research vessels by the National Ocean Survey in support of the stock assessment activity. These amounts have probably not changed much in FY 80 or 81 except for adjustments for inflation. Funds for routine stock assessment increased over earlier years, in terms of constant dollars, when the FCMA went into effect in FY 76 and 77, and increased again slightly in the following years. The current level is about 50% higher than the level through FY 73 to FY 75 (Table 4).

Research Personnel

The number of research personnel during recent years is not immediately available from NMFS (perhaps because of the rapid increase in other responsibilities of NMFS). However, totals of full-time personnel are reported to have been 1,844 in FY 1972 and 1,857 in FY 1979, during which period approximately 200 ceiling positions were shifted from traditional scientific and technical effort into other

Table 4:
TOTAL NMFS FUNDING and PERSONNEL, and RESOURCE ASSESSMENT FUNDING, FY 1973-80

Fiscal Year	Total NMFS Funding	Indexed[1]	Resource Assessment Funding[2]	Indexed[1]	Total FTP[3]
	$ thousands				
1973	51,353	38,582	9,278	6,971	1,712
1974	51,952	35,174	9,596	6,497	1,748
1975	60,068	37,263	10,654	6,609	1,707
1976	68,654	40,266	13,788	8,087	1,762
1977	83,619	46,071	16,871	9,295	1,827
1978	97,063	49,699	19,979	10,230	1,881
1979	117,719	54,149	23,128	10,638	1,857
1980	135,161	56,364	25,675	10,707	---

[1] Corrected for inflation by Consumer Price Index (1980. March only) (1967=100)

[2] MARMAP Program

[3] Full-time permanent personnel, last month of fiscal year.

Note: Each column shows 1980 as percent of 1973 as follows:

+263 +146 +277 +154 +108

Source: John P. Wise of National Marine Fisheries Service programs to support new legislative mandates (John P. Wise of NMFS, personal communication). The anomaly of increased resource assessment budgets in constant dollars and nearly level employment ceilings has apparently been accompanied by increased work done under contract and by part-time employees.

Methods

In every fishery, the stock assessment activities have started with the records of catch, of fishing effort, and of the composition of the catch by size and age if possible. To these data have been added the scientific information about the biology of the stock, its spawning and feeding habits, its habitat range and migrations, its rate of growth, and its schooling habits. Next come estimates of the changing abundance and the impact of the fishery.

The fishery catch statistics remain the major source of stock assessment information. They are required for every stock assessment furnished to the Councils and are the primary source for a majority of such stocks (NMFS, 1980, Table 5).

The other major source of information for the Councils is surveys by research vessels. These are used to estimate the adult population by netting them or by netting augmented by acoustical records, to estimate the abundance of eggs and larvae for a few stocks, to extend the knowledge of the biology of the stocks, and to measure the changing environment.

In most cases vessel surveys are the secondary source of information on the abundance of the stocks; but, for information on the species and size groups that are not caught or brought ashore by the fishery, and for the measurements of the environment, vessel surveys are indispensable.

The vessel surveys become the primary source of information on the stocks for which the fishery data are unreliable. Data are unreliable when the fishery operates on only part of the area occupied by the stock, when the fishermen are unable or unwilling to provide adequate data on the time, location, and amount of catch, and when the compilation and analysis of the fishery catch data are long delayed.

The adequacy of the fishery catch data varies with the type of fleet and with the level of acceptance by the fishermen of the record-keeping requirements. The fleets of large vessels on which it is practical to place observers can and usually do provide good information. On the other hand, the large small-boat

Table 5:
NUMBER OF FISH STOCKS ASSESSED BY MAJOR TECHNIQUES FOR EACH COUNCIL BY NMFS

Council	Number of stocks assessed	
	Using fishery statistics	Using research vessels for adult, egg, and larval or acoustical surveys
New England	12	12
Mid-Atlantic	18	18
South Atlantic	5	2
Gulf of Mexico	15	3
Caribbean	2	0
Pacific	21	17
North Pacific	28	27
Western Pacific	3	2

Source: U.S. Department of Commerce, NOAA, NMFS, 1979B fleets of either commercial or recreational fishermen which may be landing in many small ports usually provide much less useful information for stock assessment. In every fishery less satisfactory information is available if the fishermen do not accept the management programs and if they suspect that the data may be used for tax levies or other regulatory purposes.

Analysis and Delivery of Recommendations

Once the information from the fisheries and the vessel surveys is at hand, the analysis can begin. If analysis involves age determinations, as it usually does, it may require many weeks of laboratory work because automated "scale reading" equipment has not yet become satisfactory. In any case, the analysis will involve the addition of the current year's data to that previously obtained, because almost every acceptable stock assessment is based on a long series of data.

Once the analyses are completed the recommendations are prepared. These are developed from study of the alternative regulations, of which there may be dozens, and of the associated economic and social data. The most promising recommendations are then taken to the Council.

The beginning of a Council discussion of a new fishery management plan is the start of a lengthy process. The Council must plan its activities from the initial decision through the drafting stages, the public review and adoption, the Secretarial review, the promulgation of regulations, and the implementation, a process that requires from 14 to 32 months (NMFS, 1979). If the Council is amending a previous plan, it is necessary to restart part or even all of the process. And amendments of at least a minor nature must be expected annually.

Not only must the requirements of the FCMA be met but also those of the Endangered Species Act, the National Environmental Policy Act, the Marine Mammal Protection Act, the Coastal Zone Management Act, and Executive Order 12044 on Improving Government Regulations, as well as various administrative directives.

This process involves the research technology and the researchers throughout much of it. The adequacy of the technology is repeatedly judged and questioned during most of the process, and many researchers have become drawn into a recurring monitoring and information delivery process.

The Changing Character of Stock Assessment

The annually recurring review of stock assessment information and preparation of recommendations has brought a major change to the NMFS Fishery Centers.

The stock assessment methods and the early stock assessments, together with the recommendations and results, warranted publication in refereed research journals. But the repetition and minor modifications of the assessments must immediately reach the user groups--the Councils and the fishermen concerned. What was at first exploratory and path-finding research has become a monitoring and information delivery system under rigid guidelines.

This change has brought different challenges to many of the people involved. They now face a routine operation with a series of tight deadlines and a need to present the results in a different way than if they were prepared for a research journal. At the same time, the system has also brought a requirement for better understanding of the stocks, their interrelationships, and their environment. Long-continuing, more basic research is more urgent than ever, and, because of the short-term demands, the long-term need is not being met.

STOCK ASSESSMENT AND FISHERY DEVELOPMENT

Fishery research technology contributes not only to fishery management by government but also to fishery development. The FCMA includes purposes of promoting domestic commercial and recreational fishing, and of encouraging the development of fisheries which are currently underutilized or not utilized by United States fishermen, including bottom fish off Alaska (Sec. 2 [b] [3] and [6]).

The stock assessment information, when suitably presented as forecasts, provides the fishing community with indispensable information on the quantity of each stock that may be caught and the amount of fishing that the stock can tolerate without depletion (Comptroller General of the U.S., 1980). In addition, the observations of foreign fishing can provide, on the stocks not being fished by United States fishermen, information about species, methods of fishing, location, size of fish, size and mixtures of the catches, and times when fishing is best. Such information is vital for planning the construction and operation of fishing vessels and processing plants.

But additional information is also important (Pigott, 1980). The species that United States fishermen are not familiar with require different handling and processing procedures. Many of these species are small and will require different processing machinery. Almost all must be prepared in a form suitable for different and highly competitive markets. The successful development of these resources by the United States will require very different technology for fishing, handling, and processing than the existing fisheries.

In addition, continuing research is needed to insure the safety and good quality of the new products (Liston, 1980). The technological development depends heavily on information about flesh quality and its chemistry, toxins and how to avoid them, deteriorative processes, and many other laboratory-type studies.

EVALUATION OF RESEARCH ON ANTARCTIC KRILL

Many distant-water fishing nations have shown great interest in the krill resources of the Southern Ocean as a major potential source of food for animal and human populations throughout the world because of its wide distribution, its abundance, and its accessibility. Other nations, including the United States, are interested in the key role krill plays in the Antarctic ecosystem. Because of the speculative nature of information about krill's standing biomass, productivity, and commercial harvest, and because of the issues surrounding the potential impact upon the Antarctic ecosystem of an expanded krill fishery, some scientitsts argue for caution in proceeding with commercial development of the resource.

The negotiations of a regime to conserve Antarctica's krill and other living marine resources is underway (Department of State, 1978). Under domestic legislation and as party to the Antarctic Treaty and other international agreements, the United States shares a scientific and political interest with other nations in promoting scientific investigations and the conservation and management of krill resources in the Southern Ocean.

Commercial interests

Interest in the commercial exploitation of Antarctic krill arose in the early '60s, and rapidly expanded to many countries seeking action to develop the fishery. Krill's estimated abundance and its wide-spread distribution, as well as its accessibility have led several nations to actual exploitation (USSR, Japan, Poland, East Germany, Taiwan, Chile, Korea, and Spain), while others have shown an interest in investigating potential krill fisheries (Argentina, Australia, France, New Zealand, Norway, United Kingdom, South Africa, United States, Belgium, Federal Republic of Germany [German Democratic Republic], Denmark, Rumania, Czechoslovakia, Brazil, and Netherlands).

Krill are shrimp-like crustaceans, four to six centimeters long, which are widely distributed entirely around Antarctica and inhabit an area about 5,300,000 square nautical miles (Doi and Kawakami, 1980). (The United States' continental shelf fishing area is about 800,000 square miles.) In part of this area, krill form dense aggregrates called "super swarms," which are the object of the fisheries.

Recent potential yield (productivity) estimates range from 100 to 150 million metric tons annually (El-Sayed, 1977), an estimate that is two to three times the current annual production of fishes from the world's oceans.

Conventional fishing technology is well-suited to exploit krill's super swarms and vertical distribution. Over the years, improvements in locating and catching techniques have apparently made it possible to take large catches at moderate costs. The 1979 combined catch was probably over 100,000 tons (Alverson, 1980). As much as 12,000,000 tons of krill could be harvested and processed by a fleet of 1,000 vessels, but marketing constraints will severely limit the commercial harvest. Projections show a commercial harvest of two to four million tons in 1985, which is unlikely to exceed 50,000,000 tons by the turn of the century (Alverson, 1980).

Although krill is believed to be an immense protein source, U.S. fishermen have not been interested in actively exploiting it. Countries with large, idle long-range fishing vessels, on the other hand, have pushed for exploitation of living marine resources in the Southern Ocean. The United States does not have such vessels, and at present, U.S. fishermen do not see any economic advantage in leaving their domestic fishing operations to fish krill in the Antarctic. Therefore, it is unlikely that the United States will have any immediate commercial interest in krill. The frontrunners of such exploitation will probably be the Communist-bloc countries and Japan and, perhaps ultimately, Chile (Alverson, 1980).

The United States as a nation does have an interest in the key role krill plays in the Antarctic ecosystem. Krill, more than any other single-species of zooplankton in other ocean ecosystems, is an important link between phytoplankton and higher trophic forms (McWhinnie and Denys, 1978). Whales and other marine mammals, fishes, and birds of the area feed on them.

Status and problems of stock assessment

Considerable information is available on the fundamental biology and ecology of Antarctic krill (larval stages and distribution, sexual maturity, spawning, feeding characteristics, and regional differences in population densities), but critical areas of knowledge remain to be clarified (growth rates, longevity, fecundity; hydrographic features of areas of high and low population densities and transport of early larval stages; pairing and repeated spawning) (El-Sayed, 1977).

Another area which needs study is that of change in abundance. Direct estimations of krill biomass from plankton net hauls or acoustic methods are subject to variance because of the structure and irregular distribution of the swarms

(El-Sayed, 1977). This deficiency of information results in a lack of direct or accurate data on the magnitude of either the standing biomass or annual production of krill. These biological and ecological data must be gathered at diverse geographical locations during different seasons and over several annual cycles to provide a basis for judgment regarding harvestable limits. The immense geographical area occupied by Antarctic krill and the severe climatic conditions of the Southern Ocean limit many of these assessment activities.

Although these problems exist, they may not invalidate the present estimates of biomass and productivity which are broad ranges (El-Sayed, 1977). They do make it difficult to achieve the precision necessary to monitor changes in the krill population, changes which could result from a recovery of the whale stocks or a large-scale exploitation.

If a desirable commercial harvest could eventually be determined, problems would still exist with the processing and marketing of krill. The presence of fluoride in krill samples taken by Canada far exceeds the U.S. federal standards (Soevik and Braekkan, 1979). This and other problems associated with handling, processing, and distributing, as well as of development of a palatable and acceptable product, limit what can actually be harvested commercially. In addition, of course, the rising cost of fuel and the seasonality of the fishery cause economic problems that will restrain commercial harvest of krill.

Future research needs

At this time, research on Antarctic krill is basic and exploratory, rather than routine assessment. Multinational research efforts have been on-going and include surveys and explorations done by the Soviets, Japanese, Polish, West Germans, and Chileans. The United States has not done as much scientific research on krill as these countries have, but could begin by sending more scientists on foreign research vessels. Long-term research programs should be developed, and existing international collaboration on krill research should be further expanded and intensified.

Research needs include more precise estimates of the standing biomass, productivity, commercial harvest, and impact of a krill fishery upon the Antarctic ecosystem. A better understanding of the fundamental biology, the dependence of fish and marine mammals on krill stocks, and the interrelations between krill swarming and the hydrographic features of Antarctic waters is necessary before abundance estimates can be obtained. Studies are underway to refine acoustic sensing from ships or buoys, aerial surveys, and the use of satellites (El-Sayed, 1977).

Comprehensive catch and effort statistics must be collected and reported to the appropriate international agency. Methods of survey techniques, data collection, evaluation, and reporting need to be standardized and intercalibrated.

EVALUATION OF RESEARCH ON MARINE MAMMALS

Eberhardt et al. (1979) review the methods currently used to census marine mammal populations, criticize these methods, and suggest improvements and future research needs. Their review identifies three types of limitations which have constrained the quality and quantity of past marine mammal surveys: the needs for (1) better survey methodologies (i.e., improved accuracy and efficiency), (2) better technology, and (3) increased funding.

Marine mammal populations are extremely difficult to census, since they combine the inaccessibility of most fish populations with the variability in behavior of most terrestrial mammalian species (Eberhardt et al., 1979). Although past survey mtheods have met with some success for a limited number of marine mammalian species, much additional research is needed to develop methodologies capable of satisfying the requirements of the MMPA. Furthermore, since marine mammals, as a group, are extremely diverse in behavior and habitat preference, a number of survey techniques will have to be designed, each with sufficient flexibility to adapt to the particular characteristics of several species.

Curtailment of U.S. harvesting of marine mammals has drastically reduced direct acquisition data on population sizes and auxiliary characteristics (e.g., age at maturity, sex and age distribution, fecundity, survival rates) based upon catch-effort and mark-recapture procedures. In the absence of harvesting, therefore, alternate study methods based upon mark-resighting, sightings per unit effort, and direct counting have been relied upon. A major drawback to such methods, however, is that often an unknown and unestimable fraction of the population is not visible. Hence, indices of abundance are all that can be reliably obtained from many such surveys (Eberhardt et al., 1979). A major goal of future methodological research should therefore be to develop corrections for nonvisible fractions so that estimates of total abundance can be made.

Another methodological problem hampering marine mammal surveys is posed by the large areas over which many such surveys must range. In some cases, the behavioral trait of certain species to concentrate seasonally in dense aggregations (e.g., California gray whale, Eschrichtius robustus; northern fur seal, Callorhinus ursinus) can be exploited in designing efficient sampling schemes. However, many species (e.g., harbor seal, Phoca vitulina, porpoises, Stenella spp.) do not aggregate to such an extent and therefore require large-scale surveys to assess adequately their population sizes. Eberhardt et al. (1979) noted two examples of problems resulting from such surveys. In the first case, Sergeant (1974) rediscovered a large population of hooded seals, Cystophora cristata, which had not been spotted for over 100 years. In the second case, two recent estimates of the total population size of Antarctic crabeater seals, Lobodon carcinophagus, differed by an order of magnitude (Ecklund, 1964 and Erickson, 1971). Clearly, the methods needed to census animals that range over large areas deserve more research.

While it is evident that improved survey methodologies are needed to upgrade the efficiency and accuracy of marine mammal surveys, other types of improvements are also in order, most of which can be classified as technological needs. They include the development of new technology and the modification and/or acquisition of current technology.

A major requirement of virtually all marine mammal surveys is some form of observer platform. Since the number of commercial harvesting vessels has been drastically reduced, a major source of cost-effective platforms has been curtailed. Hence, NMFS has diverted its own fishery research vessels to conduct marine mammal surveys.

Such surveys could be done better by especially designed survey ships, and this would be expensive. These ships should have long-range capability, especially when operating in remote parts of the world. They should be designed for visual searching, and they should have the added capability of obtaining both passive and active hydroacoustic data. They also should be able to accommodate helicopters which could be used to extend and augment surveys. Finally, for Arctic and Antarctic work, survey ships must be ice-strengthened. To date, lack of suitable survey vessels has hampered the Bowhead Whale and Cetacean Tracking Programs in the north Pacific Ocean and the U.S. Antarctic Program (Eberhardt and Hofman, 1980).

An additional type of observer platform required, especially for large-scale surveys, is aircraft. As with ships, these platforms must have long-range capability. In the case of porpoise surveys in the eastern tropical Pacific Ocean, for example, survey planes are required to search as far as 1,500 nautical miles out to sea (Eberhardt and Hofman, 1980). Survey planes must be able to fly slowly enough to permit adequate visual searching and aerial photography. Finally, survey aircraft must be maneuverable enough to change altitude and course frequently so that observers can identify species, obtain more accurate counts, and take aerial photographs. Lack of suitable aircraft has, in the past, constrained the Tuna/Porpoise Program in the eastern tropical Pacific Ocean and the Bowhead Whale and Cetacean Tracking Programs in the north Pacific Ocean (Eberhardt and Hofman, 1980).

In addition to more and better observer platforms, marine mammal surveys require better use of aerial photography. The value of conventional photography has been established, especially for surveying large aggregrates of animals (Eberhardt et al., 1979). Attempts have also been made to employ ultra-violet and infrared photographic techniques and have met with some success (Eberhardt et al., 1979). Research is needed to improve the accuracy of these techniques and to make them cost-effective.

Tracking of radio-equipped individuals via aircraft or satellites has not been used to a great extent in marine mammal surveys. Eberhardt et al. (1979), however, state that such techniques show considerable promise and should be addressed by future research.

A final technological need of marine mammal surveys is updated navigational equipment on survey vessels and aircraft because a large number of these surveys are conducted far from shore and navigational aids.

Meeting the assessment requirements of the Marine Mammal Protection Act will be costly. Funding limitations in the past have generally constrained methodological research and technological development, have slowed the acquisition of data, analysis, and distribution, and have created shortages of necessary equipment and manpower. Most marine mammal survey programs have been severely hampered by these limitations, and it is clear that if these programs are to improve to the extent required, a major increase in financial support is needed.

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APPENDIX:

Papers Contributed to
Fisheries Research Technology Conference
21-24 April 1980, Seattle Washington

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Papers Contributed to Fisheries Research Technology Conference, 21-24 April 1980, Seattle, Washington.

1. Bevan, Donald E. and Alverson, D.L. The function of optimum yield under the Fishery Conservation and Management Act of 1976.
2. Eberhardt, L. Lee and R.J. Hofman. Existing programs, technology, and requirements relative to the conservation and protection of marine mammals in the U.S. fishery conservation zone and in the Southern Ocean.
3. Hargis, William J. An evaluation of the Federal management system for ocean research.
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11. Wolf, Robert S. The NOAA fleet related to fisheries research.
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13. Wooster, Warren S. Oceanography, ecology, and marine fisheries.

THE FUNCTION OF OPTIMUM YIELD UNDER THE FISHERY CONSERVATION AND MANAGEMENT ACT OF 1976

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Few argue that the determination of optimum yield (OY) is one of the more important tasks for the Regional Fishery Councils in their development of a fisheries management plan (FMP). The arguments come thick and fast, however, in any fishery, when we attempt to specify what is optimum yield or even how we propose to make its determination. Optimum yield is a paradox: so simple and yet so complicated an idea. The definition in Webster's dictionary suggests the reasons for the complexities inherent in the term "optimum." "Optimum: the amount or degree that is most favorable to some end or (2) the greatest degree obtained under implied or specified conditions." If we had answers to the questions "What end?" or "Whose end?" or "What conditions?" we might simplify the problem. Decision-makers no doubt would welcome a universal algorithm--obviously the more complicated the better--which would provide the required solution. This paper offers no such simple solution. The definition of Optimum Yield given to the Pacific and North Pacific Councils some two years ago was that optimum yield is what the Council says it is, but the Council has to be very careful how it says it (Crutchfield and Bevan, 1977). In defining optimum yield, the Council must take direction from the Fisheries Conservation and Management Act (Public Law 94-265), which defines optimum yield in Sec. 3 (8) as follows:

> The yield from a fishery, means the amount of fish (A) which will provide the greatest overall benefit to the Nation with particular reference to food production and recreational opportunities; and (B) which is prescribed as such on the basis of the maximum sustained yield for such fishery as modified by any relevant economic, social, or ecological factor.

The FCMA also refers to OY in Sections 2, 201, 301, and 303. One of the listed findings of the Congress 2 (a) (5) says

> Fishery resources are finite but renewable. If placed under solid management before overfishing has caused irreversible effects the fishery can be conserved and maintained so as to provide optimum yields on a continuing basis.

A major purpose of the Act 2 (3) (4) is described as follows:

> To provide for the preparation and implementation, in accordance with national standards, of fishery management plans which will achieve and maintain on a continuing basis the optimum yield from each fishery.

Section 201 (d), in setting forth the method for calculating the total allowable level of foreign fishing (TALFF), says that

> the total allowable level of foreign fishing, if any, with respect to any fishery subject to the exclusive fishery management authority of the United States, shall be that portion of the optimum yield of such fishery which will not be harvested by vessels of the United States, as determined in accordance with the provisions of the Act.

Section 201 (g) requires that OY be specified in preliminary management plans (PMP's).

The Act provides national standards for fishery conservation and management in Section 301. The first national standard, Section 301 (a) (1) specifies that

> conservation and management measures shall prevent overfishing while achieving, on a continuing basis the optimum yield from each fishery.

Section 303 (a) requires that the plan shall

> (3) assess and specify the present and probable future condition of, and the maximum sustainable yield and optimum yield from, the fishery, and include a summary of the information utilized in making such specifications;

and

> (4) assess and specify (A) the capacity and the extent to which fishing vessels on an annual basis will harvest the optimum yield specified under paragraph (3)
>
> and
>
> (B) the portion of such optimum yield which, on an annual basis will not be harvested by fishing vessels of the United States and can be made available for foreign fishing.

Any interpretation of the number of issues involved in the Act's description of OY must rest in part on the intent of Congress as revealed in legislative history.

It is our view that certain changes that occurred during the development of the legislation have altered the significance of the Act, defining its intent more clearly than the language of the final draft might suggest.

One such important change was the replacement of the term "optimum sustainable yield" with "optimum yield." Apparently the Congress sided with the views expressed earlier by Radovich (1975) that in many cases the optimum yield would not be sustainable, and Roedel (1975) that the optimum yield may, for limited periods, exceed MSY if economic or social demands so dictate. Congressman Ruppe (Legislative History p. 898), speaking as a proponent of the bill, stated that the concept of optimum yield permits the catch to be set below maximum yield or to increase the catch beyond a temporary basis as circumstances warrant. He further stated that the key to optimum yield was flexibility.

The Act does not provide a definition of overfishing, but Sec. 2 (a) (5) implies that overfishing creates irreversible effects; and the idea that exceeding OY is not overfishing seems further reinforced since the Conference Committee deleted a specific provision against exceeding OY.

Another significant change in the Act revealed by the legislative history was the linking of OY to maximum sustained yield (MSY). The drafters concurred with the views of Bevan who, commenting on an early draft (letter Sept. 19, 1975 to the Honorable Warren G. Magnuson) wrote

> I should like to suggest another definition of optimum yield, which I think is extremely important in applying management in practice. I would completely reject Option B [which suggested utilizing maximum economic yield] but point out that Option A can be defined by different interests in different ways and it may make it difficult to apply a practical application of a quantitative figure in an actual fishery. Optimum yield can be taken to mean what anyone wants it to mean. I would suggest that an analogy from navigation is useful in providing a definition of optimum yield. If we know a starting point and know our distance and direction from it, we can locate a position with exactness. I suggest that optimum yield be defined in the same way, that the base line be the maximum sustained yield, and that optimum yield be defined as a measured deviation from maximum sustained yield, together with the reasons for moving from the maximum sustained yield. This definition provides several advantages. First, in order to define maximum sustained yield, sufficient biological observations need to be taken and a sufficient knowledge of stock has to be on hand to understand how the stock will respond to various levels of fishing. And second, those interests who choose to move away from maximum sustained

> yield, and I can think of many valid reasons to do so, will be required to quantitatively state the movement necessary and what gain is to be expected from over or underfishing. If this is done, we can have some numbers which different interests can evaluate and perhaps a consensus can be obtained more easily.

Estimating appropriate yields has been an important part of fishery science. Baranov (1918). Thompson and Bell (1934), Graham (1935), Schaefer (1954), Fry (1947), Ricker (1948, 1954, and 1958), Beverton and Holt (1957), Nikolsky (1965), Pella and Tomlinson (1969), and Gulland (1969) provide a cross-section of the simplified models used for predictive purposes in fisheries management.

The Scientific and Statistical Committee of the Pacific Council (Anon., 1979) has defined MSY as follows:

> An average over a reasonable length of time of the largest catch which can be taken continuously from a stock under current environmental conditions. It should normally be presented with a range of values around its point estimate. Where sufficient scientific data as to the biological characteristics of the stock do not exist or the period of exploitation or investigation has not been long enough for adequate understanding of the stock dynamics the MSY will be estimated from the best information available.

Before considering the methods available for estimating the baseline MSY required in fishery management plans, it is well to consider the criticism of the use of MSY. May et al. (1979) in the "Management of Multispecies Fisheries," Larkin (1977) in his paper "An Epitaph for the Concept of Maximum Sustained Yield," Sissenwine (1978) and a host of economists are often quoted to substantiate claims that MSY should not be used as specified in the FCMA. Unfortunately, many have either not read behind the titles, or have confused the difference between managing to obtain MSY and using MSY as a tool in determining other yield objectives. Even Larkin provides some praise of MSY:

> In summary, from a biological point of view, the concept of MSY is simply not sufficient. Nevertheless, it should be stressed that it provides a valuable rough index of population potential.

Larkin, in the careful words of a mathematician, feels that MSY is not sufficient, but he does not claim that its calculation might not be necessary as a guide to fishery management seeking to attain some other yield.

MSY, as it is used in the FCMA, is not a goal or objective of the management plan, but a starting point that provides a common baseline. The precision

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or accuracy of its estimate may not be as important as the measured departure from MSY and the reasons for that departure. A baseline may help avoid the problem foreseen by Croker (1975) when he suggested,

> Then the viewpoint of whoever has the most political clout is declared to be optimum . . . . It's just like it has always been except that we now have a loftier sounding goal, and perhaps a more rational decision can be made.

The Council can choose from a number of methods to estimate MSY depending on the scientific information available.

1. It simply can average past catches for periods when stocks seemed stable.
2. It can estimate MSY from stock production models such as the Schaefer model or the output from the Pella-Tomlinson (1969) GENPROD computer model if catch and effort data are available.
3. It can utilize yield per recruit or dynamic pool models if appropriate growth and mortality parameters are available.
4. It may apply a spawner-recruit relationship.
5. If total biomass estimates and estimates of natural mortality are available, the Alverson-Pereyra (1969) equation, MSY = 0.5 MB, can be used.
6. It can utilize the biomass estimates from ecosystem models such as DYNUMES III, Laevastu and Favorite (1979), if they are available.

In addition to variations in the input parameters, the methods listed above operate on assumptions that vary in their difficulty of fulfillment.

This paper is not the place to review the choice of method. Scientific and statistical committees can perform that function since each plan may be unique. Reviews of the differences among some of the methods have been produced by Royce (1975), Sissenwine (1978), and Hennemuth (1977).

Conservationists and environmental groups are recently concerned that fishery management plans do not properly assess ecological interactions. In part, this attitude may reflect an absence of quantitative information about such interrelationships and, hence, about the consequence of shifts in abundance of forage fish or predators of a particular species. These concerns may result in requests to reduce MSY to accommodate material energy needs of "dependent" species. Confusion regarding the contribution of a species to other members of the biological community with which it interacts could be reduced if, in establishing MSY, the material energy lost annually from that species were specifically identified. In order to highlight mortality losses a gross annual products (GP) figure could be calculated. Gross production from a stock at a level required to produce MSY, less losses due to natural mortality, would equal MSY. That is $MSY = GP (e^{-M})$. If the values of the equation were given in a plan, then the material flow to the ecosystem could be identified.

In regard to MSY we can conclude that many authors argue convincingly that it is difficult to achieve MSY in a fishery, that the problems of MSY assessment are well known to fishery scientists, and that its estimates provide a useful tool in evaluating appropriate yields from a fishery. The Act does not require the achievement of MSY.

Calculation of departures from MSY

While it seems almost self-evident that the direction and the magnitude of departures from MSY will depend upon the goals and objectives of the Council, the experience to date shows that many Councils have great difficulty in defining their goals and objectives. It also seems very easy to confuse what needs to be done with how it must be done. The technical experts on the Plan Development Teams then must confound the process by providing options which intermingle different goals with different means of obtaining these goals. It has not been uncommon for Councils to choose among a set of complicated regualtions and then turn to their scientists to ask them what the Council has done. This procedure is analogous to impulse buying in a supermarket. We might speculate that a Council planning a banquet would first go to a supermarket and impulsively buy several baskets of groceries, turn them over to a Banquet Development Team, and ask them to provide a menu and evaluate the economic (cost of dinner), social (whether there was appropriate distribution of soup, salad, main course and dessert), or ecological (was it nutritious?) factors.

The first step in OY determination should be the definition of goals and objectives. The goal should be described in ways that make them attainable. They must be goals which can be agreed to by reasonable people, and they must be attainable by the methods or instruments of fishery management available (Royce, 1975).

It seems useful in departing from MSY to consider the deviations in two steps. The first would be to consider the ecological or biological requirements of the stock, and to define an acceptable biological catch (ABC) which would provide a spawning stock within the range producing the most desirable level of recruitment. Admittedly, the acceptable biological catch, if it provides for rebuilding, can include some economic and social considerations which may relate to the speed in rebuilding. This view of considering the biological considerations first was proposed in the report of the ad hoc meeting on the Provision of Advice on the Biological Basis for Fisheries Management of the International Council for the exploration of the Sea (Anon., 1976). It has also been adopted by the Pacific and North Pacific Fishery Management Councils in their instructions to Plan Development Teams.

While the Act does not require any minimum set of scientific information before a plan is developed, it does have some minimum standards on the kind of data to be gathered once a plan is in place. Sec. 303 (a) (5) states that any fishery management plan shall

> specify the pertinent data which shall be submitted to the Secretary with respect to the fishery, including, but not limited to, information regarding the type and quantity of fishing gear used, catch by species in numbers of fish or weight thereof, areas in which fishing was engaged in, time of fishing, and number of hauls.

In addition to the Act's requirements for catch and effort data by time and location, it would also seem essential to gather information on age, size, and sex ratios in the catch as well.

Many have called attention to the fact that while the Act requires the use of the best scientific information available, there is no requirement that the information used meet any minimum standards for quality. In practice, this apparent dilemma does not present a problem, since most of the fisheries under consideration for FMP's are economically important enough to the region that some scientific work has been done. In general, it is better to apply very sparse data than to do nothing at all, i.e., no regulation or no exploitation.

Miles, Rogers, and Collingsworth (1977) have outlined the methodological requirements of determining OY, an outline of needed research and an identification of data needs. They conclude that there is no way in which the concept of optimum yield can be given any meaning without clear specifications of the relevant economic and social objectives to be served.

They also point out that the description of national objectives and standards is so general that each council must interpret them in order to fit the conditions of the region. They suggest that economic objectives of management be stated in terms of efficiency in order that the costs of alternative choices can be measured. They suggest that relevant social objectives be established on the basis of the demands that are made on the Council by its various constitutents.

Crutchfield (1979) lists some specific elements to be considered in attaining economic efficiency:

1. The right level of catch--at which the marginal social value of the harvest is equated to the incremental social cost required to take it (including management costs).
2. The right size (age) composition of catch. No net economic gains can be obtained by allowing smaller fish to grow (i.e. where marginal increments to revenue from growth are just offset by marginal losses to natural mortality and costs of program implementation.
3. The right number and configuration of vessel-gear-fishermen units to minimize the aggregate real cost of taking any given catch (i.e. optimal factor combinations).
4. Optimal fleet deployment; no increase in yield and/or reduction in cost can be achieved by altering the area or time fished.

He also warns that economic efficiency alone is not a sufficient criterion for OY and that "economic rationalization of fisheries will usually be constrained by conflicts with other social objectives."

It seems reasonable to conclude that OY was meant to be valid over a period of time. The Act uses the modifying phrase, "on an annual basis," only when referring to the capacity of domestic harvesters to take optimum yield, and to that portion of OY which may be made available to foreign fishermen, the total allowable level of foreign fishing (TALFF). If OY were intended to be calculated on an annual basis, it could be expected that the Act would say so. At any rate, it is impossible, as a practical matter, to manage a fishery by plan amendment. The details of the plan amendment process promulgated by the Secretary of Commerce in the required guidelines make it impossible to obtain data from a fishery, analyze it, proceed through the amendment process, and communicate new regulations to the fishermen before the beginning of the next season's fishery.

If anything is clear about the intent of Congress, it is that they desire foreign fishing to be replaced by domestic harvesting and processing. They clearly spell out a process in which only fish surplus to domestic needs are made available for foreign fishing. The Act also requires that management programs promote efficiency and take into account variations in fishery resources and catches. It follows that Congress would not require an inefficient overcapitalization of domestic fisheries that would have the capacity to take any expected annual catch before a foreign fishery can be excluded. It seems much more reasonable to conclude that TALFF's are calculated for some appropriate period of time and that foreign fishing is allowed when there is a reasonable expectation that it will be carried out for more than one fishing season. It cannot be imagined that foreign fishing, as defined in the Act, was required to be called in on an irregular basis to respond to an unusual temporary surplus.

While the Act defines OY as the amount of fish which will provide the greatest benefit to the nation, it does not specify that the amount be described as a specific number or tonnage of fish. A better sense of OY would permit the description of a specification or procedure which could lead to the attainment of OY. This procedure may be particularly useful in some fisheries in which OY in weight or numbers can be accurately determined only after the season is over. Examples are the Tanner Crab and King Crab of Bering Sea and the Stone Crab of the Gulf of Mexico. In these fisheries, using a size and sex limitation, only males surplus to the reproductive process are taken. In the Stone Crab fishery, only the claws are removed and the crab returned to the water. It is possible to specify OY in other fisheries by an appropriate amount of catch that would lead to the attainment of optimum yield.

Any discussion of optimum yield should turn for the moment to the topic of uncertain numbers. Fishery scientists are used to dealing with numbers and most have had adequate training in mathematics and statistics so that they know how to deal with uncertain numbers and how to measure the degree of uncertainty. The numbers that are used in fishery plans, however, are the concern of many whose mathematical training may be insufficient, or limited to the mathematics of accounting. To bring greater understanding to those whose calculating experience has most often involved dollars, Plan Development Teams, when they have a measure of the variance around their estimates, should provide the value of both the estimate and the variance. In addition, the use of appropriate numbers of significant figures will prevent the unwary from assuming accuracy that is not warranted. In dealing with uncertain numbers, it is most important that the regulatory process avoid concern with scientifically meaningless deviations from allowable catch estimates.

A primer for OY calculations to meet requirements of the FCMA:

1. Establish MSY by the most appropriate method or a "best blend" from a number of methods. MSY, as an average over an appropriate period of time, would be expected to stand for a number of fishing seasons and would remain in the plan until new information required a plan amendment.

2. Determine the sociological, economic, and ecological goals for the fishery considered in the management plan.

3. Calculate optimum yield in a two-step process, biological and ecological factors first, then sociological, economic, and perhaps ecological factors again if they cannot be separated from social factors. While optimim yield could be considered above or below MSY, it is obvious that, if placed above, its attainment must be a temporary condition. It would seem advisable that OY set above MSY should be accompanied by some explanation of how the plan amendment process will be used to change OY in the future, so that it can be sustained.

4. Estimate the domestic harvesting and processing capacities (and joint venture requirements if applicable) and the extent to which they will be exercised.

5. Calculate TALFF by subtracting domestic requirements from OY. If on the average TALFF's were zero, no distribution to foreign fishermen would be made, even though in some years the domestic capacity was not adequate to harvest the catch. In order to calculate TALFF in this manner, some agreement must be reached as to how to handle TALFF in situations where total allowable catches may vary greatly from an average OY in individual years. For example: should there be a TALFF if we expect that domestic opportunities will not be utilized one year in ten, one year in five, or one year in three.

6. Establish specific criteria in the plans that allow an annual calculation of an acceptable biological catch and any departures for economic, social, or ecological reasons from it, to an estimated annual catch (EAC). The EAC may be a procedure, or a number, or a weight. It may or may not be a quota. The EAC taken over time should result in the attainment of OY, but it may be more or less than OY in an individual fishing season. It seems possible, in certain circumstances, that bounds on EAC, which limit its departure from OY, could be specified in the plan, so that the fishery managers working under the criteria within a plan could move only so far, without the requirement of a plan amendment.

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EXISTING PROGRAMS, TECHNOLOGY, AND REQUIREMENTS RELATIVE TO THE CONSERVATION AND PROTECTION OF MARINE MAMMALS IN THE U.S. FISHERY CONSERVATION ZONE AND IN THE SOUTHERN OCEAN

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This paper addresses two aspects of the request of the Office of Technology Assessment for review of Federal fisheries research technology. These are (item c of the list furnished) "Evaluation of Methods, Techniques, and Models Developed for the Management of Marine Mammals, particularly in response to the Marine Mammal Protection Act"; and (item m) "Evaluation of Research on Antarctic Marine Living Resources."

BACKGROUND

The Marine Mammal Protection Act (P.L. 92-522, 21 October 1972) established a moratorium on the taking of marine mammals in U.S. waters and/or the importation of marine mammals and marine mammal products into the U.S. The Act provides a special exemption for the taking of marine mammals by certain natives for subsistence, handicrafts, and clothing. "Take" is defined in the Act as harassing, hunting, capturing, or killing, or attempting to harass, hunt, capture, or kill any marine mammal.

The Act provides for waiver of the moratorium and return of management to the states. It also provides for issuing permits to take marine mammals for purposes of public display, scientific research, and incidentally during fishing operations. Under the Act, the Secretary of Commerce is responsible for cetaceans and pinnipeds other than walrus, while the Secretary of the Interior is responsible for all other marine mammals (i.e., walrus, manatees, dugongs, sea otters, and polar bears). The Secretaries of Commerce and Interior have delegated responsibilities to the NMFS and the U.S. FWS respectively.

The Act created the Marine Mammal Commission and charged it with overviewing all U.S. activities bearing upon the conservation and protection of marine mammals. The Commission consists of three individuals, knowledgeable in the fields of marine ecology and resource management, who are appointed by the President. The Commission has an executive director and staff, and a nine-member Committee of Scientific Advisors on Marine Mammals.

The primary objective of the MMPA is to maintain the health and stability of the marine ecosystem and, whenever consistent with this primary objective, to obtain and maintain optimum sustainable populations of marine mammals. The Act defines "optimum sustainable population" (OSP) as follows:

> The number of animals which will result in the maximum productivity of the population or the species, keeping in mind the optimum carrying capacity of the habitat and the health of the ecosystem of which they form a constituent element.

"Optimum carrying capacity" is defined in the Act as follows:

> The ability of the given habitat to support the optimum sustainable population of a species or population stock in a healthy state without diminishing the ability of the habitat to continue that function.

The statutory definition of OSP has been interpreted by the NMFS, for application in the management context, as follows:

> Optimum sustainable population is a population size which falls within a range from the population level of a given species of stock which is the largest supportable within the ecosystem to the population level that results in maximum net productivity. Maximum net productivity is the greatest net annual increment in population numbers or biomass resulting from additions to the population due to reproduction and/or growth less losses due to natural mortality.
> (50 CFR 216.3)

This operational definition of OSP has been used in making decisions concerning the status of porpoise stocks impacted by the yellowfin tuna purse seine fishery (Smith, 1979), and in the waiver of the moratorium on taking marine mammals in Alaska (44 FR 2540-54, 11 January, 1979). A crucial development in practical application, supported by various research studies, is that the MNP level is substantially higher than the original logistic-curve MSY level (50% of maximal population levels). A workshop convened by NMFS in 1979, in connect-

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tion with the tuna-porpoise problem, concluded that the appropriate level is at least 65%, and evidence from studies of baleen whales and other species suggest that it may indeed be higher yet (op. cit.).

In 1976, the MMPA was amended by Section 404 of the FCMA to include within the term "Waters under the jurisdiction of the United States" the waters of the U.S. FCZ established by the FCMA.

RESEARCH/MANAGEMENT PROBLEMS AND INFORMATION NEEDS

In the context of this workshop, the principle research/management problems associated with marine mammals in the U.S. FCZ are the following:

1. The protection and recovery of endangered species such as the West Indian manatee, the Hawaiian monk seal, and the bowhead whale.
2. The incidental take of porpoise and other species during commercial fishing operations.
3. The nature and effects (on the fish stocks, the marine mammal populations, and the fisheries) of competition between marine mammals and fishermen for the same fish resources.
4. The impact of marine mammal-caused gear damage, fish damage, and fish loss on sport and commercial salmon fisheries and other fisheries in Alaska, Washington, Oregon, California, and elsewhere.
5. The possible direct and indirect effects of offshore oil and gas development on marine mammal populations and habitats in waters off Alaska, California, New England, and elsewhere.

With respect to the Antarctic, the principle research/management problems concerning marine mammals are the following:

1. The regulation of commercial whaling and the rebuilding of depleted populations of blue, humpback, fin, and sei whales.
2. The possible effects of krill harvesting on the carrying capacities of krill-eating whales and seals and the rebuilding of depleted whale stocks.

To define better and resolve these and other problems, we need reliable information on such things as (a) the status (present distribution, abundance, and productivity vs. historic distribution, abundance, and productivity) and trends of the affected marine mammal populations; (b) the habitat use patterns, habitat requirements (particularly food requirements), and essential habitats of the affected marine mammal populations; (c) the species, numbers, ages, sexes, and reproductive condition of marine mammals taken incidentally during fishing operations; (d) the nature and extent of marine mammal-caused gear damage, etc., the status of the affected fisheries; and (e) the probable effects of oil, noise, and other contaminents--from offshore oil and gas development and other sources--on the behavior, survival, and/or productivity of individuals and populations that could be exposed to oil from an oil spill, noise from ship traffic, or drilling rigs, etc.

EXISTING PROGRAMS AND TECHNOLOGY

More than ten federal agencies are conducting or supporting research into the conservation and management of marine mammals. These include the National Marine Fisheries Service, the U.S. Fish and Wildlife Service, the National Science Foundation, the Marine Mammal Commission, the Bureau of Land Management, the Office of Naval Research, and others. The programs of particular interest, relative to this conference, are (1) the Tuna/Porpoise Program administered by the Southwest Fisheries Center of the National Marine Fisheries Service, (2) the North Pacific Fur Seal and Bering Sea Ecosystem Programs administered by the Northwest and Alaska Fisheries Center, (3) the Bowhead Whale and Cetacean Tracking Programs administered cooperatively by the National Marine Mammal Laboratory of the Northwest and Alaska Fisheries Center and the Bureau of Land Management's Anchorage OCS Office, (4) the Cetacean and Turtle Assessment Program (CETAP) being conducted in the northeast by the University of Rhode Island under contract to the Bureau of Land Management's New York OCS Office, and (5) the U.S. Antarctic Research Program administered by the National Science Foundation's Division of Polar Programs.

The Tuna/Porpoise Program

The principle objectives of the tuna/porpoise program are to (a) develop gear and techniques which will reduce the mortality and injury of porpoise taken incidentally by the yellowfin tuna purse seine fishery in the Eastern Tropical Pacific and (b) assess and monitor the status of the impacted porpoise stocks. As part of its assessment and monitoring program, the Southwest Fisheries Center has conducted three porpoise surveys in the Eastern Tropical Pacific. It also is developing a satellite-linked radio-tracking system to determine better the spatial and temporal distribution of the effected porpoise stocks.

A pilot aerial survey of a limited area was conducted in 1974. Large-scale surveys were conducted in 1977 and in 1979, using both aircraft and two research vessels, in an area of about 3,500,000 square nautical miles in the Eastern Tropical Pacific. An extensive inquiry was instituted to select suitable aircraft, and several types were actually used. The outcome was that the only available aircraft suitable for low-level visual searching and possessing adequate maneuverability are those built in the 1940s. Much of the actual searching was done with PBY "Catalina" aircraft. None of the available aircraft had an adequate range, since searching some 1,500 nautical miles out to sea is required. In one survey, a more modern aircraft, but still of 1950s vintage, was used, but was found basically unsuitable.

North Pacific Fur Seal and Bering Sea Ecosystem Programs

The basic objectives of these programs are to (a) assess and monitor the status of the North Pacific fur seal herd and (b) to develop population and process models which can be used to identify research priorities and optimal management strategies relative to the fur seal, fishery resources, and other resources of the Bering Sea. The assessment and monitoring program has been reasonably successful and, at the present time, is being reviewed and revised by the National Marine Fisheries Service. The modelling programs, to date, have been less successful, primarily because of critical data gaps, and will be evaluated at a workshop to be held at the Northwest and Alaska Fisheries Center on April 29 and 30 and May 1, 1980.

The Bowhead Whale and Cetacean Tracking Programs

The principle objectives of these programs are (a) to assess and monitor the status and trends of the North Pacific bowhead population, (b) to determine how the population is being or might be affected by subsistence hunting and offshore oil and gas development, and (c) to develop a system for radio-tracking bowheads and other whales. The survey program has been on-going for several years and includes ship, shore, and aircraft observations and counts, primarily in the Western Beaufort Sea. The radio tracking program is in the developmental phase and, until recently, consisted of several more-or-less discrete programs, directed at different species in different areas, and funded independently by the Office of Naval Research the National Aeronautics and Space Administration, the National Marine Fisheries Service, and the Bureau of Land Management. Recently, these projects have been coordinated through the Marine Mammal Marking and Tagging Office which has been transferred from the National Fish and Wildlife Laboratory in Washington, D.C. to the National Marine Mammal Laboratory in Seattle, Washington.

The survey program, which has used a variety of ships and aircraft, including NOAA research ships, Coast Guard icebreakers, and twin engine aircraft, has been hampered by the lack of suitable long-range aircraft and the limited number and availability of ice-strengthened ships. The development of the radio-tracking program has been hampered by the limited availability of suitable tracking platforms (ships and aircraft), problems with the radios and antennas, difficulty in developing a safe and reliable method for attaching the radios to the whales, and failure--to date--to adapt successfully existing technology for tracking via satellite.

The "CETAP" Program

The principle objectives of the "CETAP" program are to determine the species composition, the spatial and temporal distribution patterns, and the abundance of large cetaceans in the offshore coastal area between Cape Hatteras, North Carolina and the U.S./Canadian border. Transects of the area are being flown, at regular intervals, with a four-place, twin engine, high-wing Cessna 337 and a low-wing, twin engine, seven-place Beechcraft AT-11. Photographs taken from the planes are used to document species identification, and supplementary data are being collected through a Platforms of Opportunity Program (POPs). Inclusion of a radio-tracking project was considered when the program was in the planning phase, but was rejected when it was determined that the necessary technology was not yet available.

The U.S. Antarctic Research Program

The U.S. Antarctic Research Program is a multi-disciplinary effort consisting of two activities: (1) scientific research and (2) operation support. The program has included shore-based seal surveys and radio telemetry studies in McMurdo Sound (Ross Island) and Arthur Harbor (Anvers Island); icebreaker and helicopter supported surveys of seals in the Weddell, Bellinghausen, Amundsen and Ross Seas; and a variety of seal and whale studies--primarily in the vicinity of the Antarctic Peninsula--supported by the R/V Hero. It also included a pilot aerial/photographic seal survey--using ski equipped C-130 aircraft--which, while successful, was abandoned because of cost, the limited number of and competing demands upon available aircraft, and operational limitations imposed by the limited number of airstrips in the Antarctic.

The program has been aimed at providing basic information on the biology and ecology of Antarctic seals and whales and, to date, has not been directed specifically at providing information needed to manage seals and whales or the ecosystem of which they are a part. (Virtually all of the data now available on population levels of Antarctic whales, and nearly all other whales, has been derived from catch-effort statistics obtained through commercial whaling.) The program has been limited, primarily, by the unavailability of and competing demands upon icebreakers and the R/V Hero. [1]

The need for an expanded biological research program in the Southern Ocean is generally recognized and, to better determine program needs, the National Academy of Sciences recently has been contracted to conduct "An Evaluation of Marine Ecosystems Research in the Antarctic." The study, sponsored by the National Science Foundation, the National Oceanic and Atmospheric Administration, and the Marine Mammal Commission, is scheduled to be completed in late 1981.

ASSESSMENT OF EXISTING TECHNOLOGY

As noted in the preceding discussions, available technology, particularly ships and aircraft, is insufficient to assess or monitor marine mammal populations in either the U.S. FCZ or the Southern Ocean. For example, virtually all of the data now available on population levels of Antarctic whales, and nearly all other whales, has been derived from catch-effort statistics obtained through commercial whaling. With the depletion of exploited stocks and, subsequently, reduction of commercial whaling (now restricted essentially to minke whales in the Antarctic), there are, in effect, no data sources to monitor either recovery of endangered whale species, or the impacts of the developing krill fishery on the remaining stocks.

The present prospects for monitoring whale populations in the Antarctic are largely restricted to any continuation of minke whale harvest and, possibly, to efforts assessing abundance of humpback whales in near-shore migratory corridors and breeding grounds. Since it now appears evident that minke whales have increased in abundance by virtue of reductions in the abundance of other whales (and the consequently reduced competition for krill), it is doubtful that the trends of minke whale populations will provide suitable monitoring data for the critically low levels of other species (principally blue, humpback, and southern right whales).

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[1] In this context, it should be noted that virtually all studies of the Southern Ocean have been limited to the austral summer.

There is thus a major need for a means of directly monitoring endangered whale stocks in the vast regions of the Southern Ocean. Additional requirements exist for assessing abundance of other species, including several seals, penguins, and other seabirds. These krill-dependent species will be affected by the developing krill fishery, and could serve, to some presently unknown degree, as indicators of the overall well-being of marine resources likely to be affected by the developing krill fishery.

A major need is for the long-term availability of an ice-strengthened vessel capable of long-distance surveying, geared for visual searching, and fitted with sonic equipment designed for both passive (hydrophonic) and active (sonar) acquisition of data on whales. The vessel should be designed for fuel economy and would need to transit long distances rapidly (between survey areas). Many of the available ships (e.g., icebreakers of various classes) are unsuitable for this task. The vessel should carry helicopters to extend the survey range and to permit sampling and surveying of other species (seals, penguins, and seabirds); it could be utilized in the Arctic for surveys of the endangered bowhead whale and the North Pacific walrus; and it might also be used to survey porpoise in the Eastern Tropical Pacific.

The second need is for a long-range aircraft dedicated to, and specifically designed for aerial surveys. This aircraft would, among other things, be used for surveys of porpoise in the Eastern Tropical Pacific and of bowhead whales, other cetaceans, and walrus in the Bering, Chukchi, and Beaufort Seas. It is quite possible that a suitable aircraft also could be operated in some of the Antarctic areas for assessment of both whales and seals. Conversely, a suitable vessel with helicopters, as described above, might fulfill parts of the requirements for the porpoise and other marine mammal surveys.

Development of a suitable aircraft would be likely to require substantial capital outlay for modification of an existing design. An engineering survey probably would be needed before much more could be said as to requirements. It should be noted, however, that various efforts to use photography and the several other possibilities (infrared, radar, ets.) were generally unsatisfactory for various reasons, primarily cost.

The third need is to develop a safe and reliable system or systems for tracking both seals and whales. On-going efforts in this area seem promising, but they need to be evaluated more fully, particularly those directed toward the development of tracking via satellite. The potential for remote sensing, via satellites and high-altitude aircraft, also should be investigated.

Finally, we need to improve population and process models which evaluate alternative management strategies and to set catch limits on whales, seals, and other marine living resources.

SUMMARY AND CONCLUSIONS

Meeting the intents and provisions of the Marine Mammal Protection Act depends on better assessment of the status, trends, and essential habitats of marine mammal populations and on determination of how these populations and habitats are being, or might be affected by commercial hunting, subsistence hunting, offshore oil and gas development, etc. Programs responsive to these needs have been and are being developed by the responsible Federal and state management agencies, but the effectiveness of the programs is being limited, in part, by the limited availability of ice-strengthened survey ships, long-range survey aircraft, and radio-tracking technology. We need, therefore, to (1) construct or modify an existing ship or ships for marine mammal survey in the Antarctic, the Arctic, and elsewhere; (2) construct or modify an existing aircraft to conduct effective and efficient long-range visual surveys of porpoise and other marine mammals in the Eastern Tropical Pacific and elsewhere; and (3) expedite efforts to develop a safe, reliable system for tracking marine mammals via ships, aircraft and, especially, satellite.

AN EVALUATION OF THE FEDERAL MANAGEMENT SYSTEM FOR OCEAN RESEARCH

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INTRODUCTION

To evaluate the efficacy of any research management system, one must first establish the purposes of the research intended to be accomplished by that system. Fishery research is intended to provide understanding of the fishery resources (the basic stocks) and their environmental requirements and interactions, of the environment itself, of fisheries-related activities, of fishery product consumers, and of the promises, potentialities, and problems of each. The prime reason for governmental involvement in fishery research is to allow effective utilization of the fishery resources available to that government (most fishery resources are common property) within the prevailing technological, political, economic, and sociological constraints; and at the same time to foster and protect (the latter where necessary) the resources and the socioeconomic activities related thereto. Thus, a primary purpose of marine fishery research and development is to provide information to allow for the most effective use of the living resources of the World Ocean and its marginal waters.

If the fishery research system has available to it the scientific and socioeconomic information required to permit reasonable management of the fisheries and the resources (stocks) on which they depend, the research program is successful. The information, however, must be available not only to scientists but to the management apparatus--the decision-making system--as well. Thus, the availability of a suitable communications system between science and the decision-making apparatus is an important link in the fishery management system. The communications link must transfer information both ways: scientific and technical data to managers, and management needs and experience to science.

Unfortunately, no amount of scientific evidence about the fisheries can help if the management system is incomplete, inept, or otherwise lacking. The management system must be able to use information effectively, make sound decisions, implement the necessary management measures, and monitor and enforce them, otherwise no amount of scientific knowledge and/or advice will help.

Presumably, in an ideal resource management system with computers and adequate operators and operations in all important roles, and with complete scientific and socioeconomic data and no competing, distracting, or detracting forces, managment decisions would be easy--almost automatic--and mistakes would be few. The fishery management measures it adopted would be complete and perfect. But no such system will ever exist, and we can only strive to make those that we have as effective as possible: The existing overall fishery management apparatus is too complex; and there are too many opposing interests and too many unknowns, and perhaps even unknowables, to permit a perfect system.

Since fishery management must deal with natural phenomena, i.e. biological, chemical, geological, and physical aspects, knowledge of these features as well as of those relating to human society--both scientific and socioeconomic knowledge--are essential. Most fishermen, industrialists, and government managers, i.e. those who make the large and small decisions which affect the fisheries, are aware of their dependency on science and technology, though at times they do not overtly exhibit such awareness, often choosing to denigrate or even ignore scientifically developed information. Management often exhibits a schizophrenic attitude toward science in this and other areas. Fortunately over the long-term, since the early 1800s, fisheries science has been able to grow and accomplish despite the wavering support, benign neglect, denigration, and occasional outright opposition of fishery management groups, public and private. Today fishery scientists can usually provide more useful information and advice than the social system can, or is willing to, use effectively. Even so, fishery science has much to learn about many of the natural, socioeconomic, and political phenomena involved in fishery management. Before fishery managers, public or private, can be fully served, much new remains to be learned, especially about the last two subjects, and much of current knowledge and wisdom should be re-examined.

To determine the effectiveness of fishery science and fishery science management, we should look at how well the actual informational needs of the fishery management system are being met, but that is not easy. Time-tested, objective evaluations are few. So many of the decision-making enforcement and monitoring devices developed and established for fishery management have been so imperfect that it is impossible to rely on experience and historical observations and measurements to evaluate objectively the utility of the scientific data and advice employed by examining the accomplishments of those instrumentalities. Hence the task in hand--that of carefully evaluating the effectiveness of research management, preferably through concrete results or quantitative examples of more productive fisheries or larger stocks--is difficult! We can only use the experience and data at hand and compare them against an idealized management system and idealized results. In this light we can decide what managers need to meet established objectives and goals, and we can then evaluate science's ability to satisfy management's hypothetical or idealized needs. From this, we can proceed to plan how to fill the gaps and make improvements

ORGANIZATION FOR MANAGEMENT

Because most fishery stocks are common property resources, fishery management is largely in the hands of governmental and quasi-governmental (governmentally established, sanctioned, and supported--like the Fishery Management Councils) agencies. To be sure, the various fisheries industries are involved in management, but largely of their own activities rather than of the basic fishery stocks. Except for those engaged in fishery-product farming or mariculture in some form, most private fisheries organizations are hunters, processors, movers, and purveyors of natural resources originally taken from the commonweal. Hence, governments play the major role in improving, fostering, and providing access to the fishery resources and regulating the fisheries. They also attempt to deal with the socioeconomic and political activities involved. Governments also play the major role in preserving, restoring, or allowing the dissolution of fishery environments, and in doing research on both the resources and environments, and finally in providing access to information and advice.

The governmental management of the marine fisheries and the resources on which they depend is divided between the states and the federal government, with the latter assuming responsibility outside of the territorial seas (or even inside when preemption is required and legally sanctioned). Though hints that such might come to pass are increasing, preemption of stock management and control of "hunting" inside the territorial sea has not occurred. The federal government, however, has long since taken control of interstate commerce of fishery resources and all other food products--and thus exerts control over some aspects of all of the fisheries regardless of whether the products are harvested inside or outside of the territorial seas.

Responsibility for management of fishery stocks and fishery activities outside of the territorial seas and out to the two-hundred mile limit is vested in the Department of Commerce which, under the powers granted to it by the Fishery Conservation and Management Act of 1976 (PL 94-265), uses or can use its National Marine Fisheries Service and the quasi-governmental Regional Fishery Management Councils for management plan development and advice and can use the NMFS regulatory apparatus plus the United States' Coast Guard for enforcement. The State Department, the Secretary of Commerce, and the councils are involved where foreign fishery treaties or allocations to foreign fishermen from stocks of or in the Fishery Conservation Zone (FCZ) are involved. Fisheries for such highly migratory species as the wide-ranging tuna have their own management apparatuses.

The Fishery Management Councils, Managers of the FCZ

On the Atlantic Coast, three fishery management councils, the New England, Mid-Atlantic, and South Atlantic, are charged with development of fishery management plans (FMP's) for fisheries operated within the FCZ. Their East-West seaward boundaries of responsibility largely conform to the state lines of the states bordering the regions. The Gulf is served by a separate council, as is the Caribbean. At times these councils must communicate and work together since the fishery stocks and the fishing industries which depend upon them often range through the management area of more than one council. Though their decision-making powers are vested in the appointed voting members, each of the councils has a professional staff and is served by advisory committees, which can be drawn from interested members of industry, the public, technology, and other fields. Each has a Scientific and Statistical Committee, supposedly consisting of competent professionals from the region. Each is served by the NMFS regional office apparatus and has direct and indirect access to the NMFS regional fishery research apparatus as will be described more fully below. On the staff of each Atlantic and the Gulf Coast council is at least one, perhaps more, fishery scientist. Further, the councils are empowered to contract for special scientific data and advice as needed. Thus, the fishery management councils do not lack for access to the services of the scientific and technological community.

Each council is peopled by the principal marine fishery management officers of the states in its region and by the NMFS Regional Director, all of whom, among others, are voting members. Representatives of the two regional marine fishery commissions and of the other councils as well as of the Coast Guard, State Department, and the Fish and Wildlife Service (FWS) of the Department of the Interior (DOI) are non-voting members. Consequently, the councils do not lack for access to regional and national management agencies and the competence and information they possess.

To reiterate, the councils (the offshore fishery management bodies) have access to the scientific, technological, and government-management competence extant in their regions--and even outside. They also can employ cooperative industry, consumer, and other public representatives as well as others in their preparations for and conduct of deliberations. They do not lack access to competent information, wisdom, and advice!

The States, Managers of Inshore Areas

All coastal states have agencies which are responsible for managing their fisheries. Many state fishery management agencies deal with both freshwater and marine fish (and some wildlife as well); but most in coastal states maintain special organizations to deal with marine fishery problems. Most also regularly work with the federal agencies concerned with marine fisheries (NOAA, NMFS, DOC, and FWS or the DOI).

For assistance in the management of their inshore fisheries, state management bodies may draw on their own resources for expert advice. Most maintain research and monitoring units, though they are of uneven quality, quantity, efficacy, and availability. The few lacking such internal capabilities can use state-supported fishery research capabilities provided by sister agencies or by cooperative research and advisory institutions. Too, they may contract, using their own or pass-through federal monies (from NMFS, National Oceanic and Atmospheric Administration [NOAA], Department of Commerce [DOC]) for research and advisory services. Most of the states and their marine fishery management agencies participate in the congressionally mandated and approved regional marine fishery commissions pertaining to their region. Two serve the Atlantic and Gulf Coasts. Through these commissions, state managers have access to the several regular advisory committees of the commissions and to the various voting commission units themselves, i.e. the gubernatorially appointed state fishery management, state legislative, and state industry representatives, who include persons with scientific and statistical expertise, as well as industrial and managerial persons. The NMFS also participates in commission activities.

Recently the State/Federal program has begun to provide special fishery committees and subcommittees to develop plans for more effective management of inshore, interstate fishery stocks, and fisheries. Scientists and other specialists are involved in the work of these committees. Inasmuch as the state management agencies, the NMFS, regional and national fishery scientists, and other specialists participate and regular communications exist between them and the fishery management councils, the results of their work and their knowledge are available to the councils and to Commerce (DOC) as well as to the state management organizations.

The Sea Grant apparatus was designed to provide certain scientific and advisory services to marine resource managers--among them the fishery units--and many or most do. Interaction occurs between the Sea Grant apparatus and these fishery management organizations participating in Sea Grant programs do regularly consider the needs of fishery managers, private and public, in their research programming; and the National Sea Grant Office has actively encouraged, indeed orchestrated, their efforts. Many provide regular extension-type advisory services to governmental as well as private managers.

From the discussion above it is clear that the management agencies responsible for both offshore and inshore marine fishery activities and the stocks on which they depend have direct or indirect access to the entire spectrum of organizational and individual competence in fishery science and allied scientific and technological fields, including social science and allied scientific and technological fields, including social science. They may have to pay for skills outside of the readily available portions of apparatus mentioned above, but such assistance is available. Of course professionals in other nations may be somewhat removed and difficult to use, but state fishery managers have access to the best in fishery data and advice that the country and the world affords, as do the councils. These executive management units and the other state and federal executive agencies and legislative bodies (which also control certain aspects of the fisheries and the fishery resources and the social, economic, political, and natural environments which they both must survive and deal with) have access to scientific and technical information and advice. They may not ask for it, or if they ask for and receive such assistance, they may ignore it or be unable to use it for various reasons (or the information they receive may be inadequate to their needs); but competent scientific and engineering assistance is available! Generally speaking where scientific and technical aid is not sought, heeded, or used, the fault is not with the scientific community. From time to time communications gaps develop which impair the quality and utility of transfer between science and management, but with persistence and attention management will be given the best that is available.

FISHERY SCIENCE AND TECHNOLOGY

Evaluation of the ability of fisheries managers to receive, assimilate, understand, and apply scientific data was not our task in preparing this paper, though it should be done by someone. Evaluation of the sufficiency of the data and advice and of the organizations that gather and disseminate such data and dispense the advice is! Also at question is the sufficiency of technology as applied to research and perhaps even to science/management interactions. As indicated above, communications are often ineffective. In such situations, communications specialists and the latest technological aids should be involved. Where difficulties persist, new communications devices may have to be employed, but we must remember that many new council members have little advance preparation for the tasks they become involved in and little experience with the methods of fisheries management and of fishery science. The same is true for some state fishery managers. This special problem must be anticipated and dealt with.

Adequacy of Scientific and Technical Information About the Fisheries

A principal factor which limits the utility of scientific and technical information is its adequacy. If information is inaccurate or limited in scope and does not reflect reality or cover the many facets and complex interactions involved in management of fisheries, fishery resources or fishery habitats (the environment), then the value and the utility of advice is limited. Where gross gaps in coverage or general inaccuracy are involved, data and advice can be worthless to the managers and inadequate in enabling effective management actions.

The areas of greatest weakness in our fisheries management information system are the social sciences--fisheries sociology and fisheries economics. It has been my experience, as a fisheries management council member for four years and a technical advisor to fisheries for over twenty, that sufficient sociological and

and economic data are lacking for all fisheries. Ironically we know very little yet these are often the most troublesome areas for fisheries managers. Fishing, processing, storing, transporting, preparing, selling, and consuming are human activities. The fishery populations involved are merely the raw product--the basic commodity. Often we can evaluate the status and availability of the product qualitatively and quantitatively and advise how best to catch and handle it, but we know little of the sociological or economic forces which act on all stages of the fisheries--the human activity. Yet the people and social organizations which make up the fisheries and the economic and political forces which affect them are of prime importance.

Fisheries research has been underway for several hundreds of years in the United States (Thomas Jefferson wrote and commented on Grand Banks' Fisheries shortly after the establishment of this republic) and even longer in Europe; but only recently has the need for such information been widely recognized and the skills of social scientists been employed. Even now, however, these sectors of fisheries research are the weakest and the hardest to develop continuing and adequate support for, and are the first being offered up in efforts to reduce the federal fishery management budget.

Incidentally, in one way or another the federal government provides the majority of the money for all of fisheries research both in the federal government and outside. The states contribute, but to widely varying degrees. Even in states with active research programs federal funds are important. Industry supports or does very little research on its own except for closely parochial scientific and/or technological work--mostly routine.

Organizationally speaking, most federal, state, and academic fishery research activities are weakest in support and conduct of the "social sciences" of the fisheries. Though this shortcoming is diminishing, it remains the weakest link in the system. In this aspect, all fishery research organizations, especially federal and state programs, are short.

It is difficult, of course, to do scientific investigations of individuals and their food preferences, of the social forces active in fishing communities, of economic interactions between segments of the fishery, and of political constraints, partly because these subjects are not as amenable as biological and environmental phenomena to scientific manipulation, and partly because methodology and technology of social research is relatively primitive. These aspects are improving but need attention. Anecdotal information which many social sciences employ to a large degree has its limits, and experimenting with humans by themselves and in groups is difficult. Reinforced appreciation of the need for such data and more adequate financial support for relevant social science and social engineering activities are required before this deplorable situation will improve markedly.

The Status of Fisheries Knowledge and Research

Compared with the other scientific areas mentioned above, the status of knowledge of fishery stocks themselves and their comings and goings (fisheries biology) is more advanced. Fishery science can evaluate the status of stocks and indicate their present condition, their probable movements, and can even predict their future conditions with some confidence. It should be noted that most of these evaluations and predictions are based upon continuation of average or "normal" climatic and environmental conditions. Where normalcy does not obtain, they become less useful. There are a number of weaknesses in our basic knowledge of the biology and ecology of fishery organisms, their detailed response to normal, and especially abnormal, environmental conditions. We know what they do and when they can be expected to do it under average conditions, but frequently the why is unknown and cannot be predicted!

Despite shortcomings in knowledge, the estimates of potential yields in terms of maximum sustainable yield (MSY) and other such yield parameters are generally reasonable and useful. The forces affecting fishery populations are sufficiently well-understood to allow reasonable predictions or the effects of large scale, over- or under-fishing, barring intervention of natural or man-made disasters. There are limitations of accuracy, but at present conservatism covers for whatever lacks of accuracy, precision, and predictability there are--as it should. Of course managers would prefer to be allowed closer margins--as they should; but at present they can presume sufficient familiarity and reliability on the part of fishery science to take effective managerial action.

Our ability to monitor many fishery stocks offshore and inshore is reasonably good. Adequacy of our present and continuing efforts at monitoring them is another matter. We sometimes are forced to do, or do of our own volition, less than we are technically capable of. Especially difficult is estimation of fishery effort and catches-per-unit-of-effort, not because it can't be done technically, but because of reluctance of fishermen, commercial and recreational, to provide adequate data. Furthermore, routine surveys and monitoring are not popular with scientists or science financiers. Of course, data on commerical fishing activities is easier to get, and much useful intelligence is routinely available from the fishery landings and statistical services now conducted by NMFS and some states. The activities and successes, however, of large groups of recreational fishermen are not monitored at all, or very poorly. Effort estimates are not readily available for either group.

Even more sketchy is available knowledge of the socioeconomic effects of over- or under-fishing, allocation and catch controls, gear efficiency improvements and modernization, and other aspects. Thus, these aspects are most difficult to estimate or predict.

Increased and continuing efforts should be made to understand long-term as well as abrupt changes in populations and the factors that influence them. Cause and effect are at work, but the possible numbers of causes and effects are large and difficult to understand and predict. Unravelling their mysteries will remain difficult for some time to come, but the effort must be made to allow improved management of fishery stocks and of the fisheries themselves. Nonetheless, the information on stocks and advice on stock-management which fishery science can now give to managers is useful!

To eliminate those shortcomings that do exist, we must increase our monitoring and surveillance of stocks and fishing activity to levels sufficient to allow improved understanding and mathematical modelling and prediction. Not only must fisheries research activity along these lines be increased but technology, including hard- and soft-ware, of monitoring, modelling, and prediction must be improved to permit tighter estimates and predictions and to allow maximum utilization of fishery stocks while assuring their useful survival.

Lacking in most fishery-related physiological, ecological, and environmental research is detailed understanding of the environmental requirements, tolerances, and interactions. Few really reliable water quality standards, based upon soundly established criteria, exist for estuarine and especially for coastal and oceanic waters. Without adequate standards, effective water quality management is difficult. Part of the reason criteria and standards do not exist is the lack of data on the actual requirements and tolerances of fishery organisms. Some of this lack can be eliminated by more attention to establishment of these factors in rigorous laboratory and field efforts. As mentioned below, ability to culture and hold necessary quantities of experimental organisms is critical to such activities, but the need for long-term joint observations of environmental conditions (atmospheric as well as oceanic) and fishery populations is equally great.

New techniques such as remote sensing will help greatly, but the first requisite is the decision to conduct such work, followed by determined and continued efforts to accomplish it. Much can be done, even without new technology; but determination to do it and adequate administrative, financial, and professional support are required. As indicated above, continuous field and laboratory surveys and monitoring efforts are rarely very popular with scientists, and, if they are undertaken at all, are often eliminated or reduced when programmatic *ennui* sets in or budgets are cut. Survey and monitoring must be conducted and must include careful observation of all critical ecological parameters. "All" includes the metereological and climatological, as well as the essential biological, chemical, geological, and physical oceanographic parameters of importance.

Such data are essential to development of useful ecological and populational models of different types as well as to preparation and presentation of advice to fishermen, governmental managers, and other fishery-management decision-makers.

Another important area in which technology for research exists (of course it, like all scientific areas, can benefit from hardware and software improvements), but little action occurs, is in studies of the impacts of predation and especially of the effects of diseases on all types of fishery populations. For many fishery species--even economically important ones like oysters, mussels, hard clams, and blue crabs, which have been studied for over a century--the normal cytological, histological and organismic patterns are not adequately known, much less the abnormal manifestations of sickness, poor nutrition, or inadequate or debilitative or destructive environmental conditions. Thus, careful studies of the effects of such factors on population levels are severely restrained.

Specific studies of the effects of viruses and virus-like organisms, bacteria, protozoans, and metazoans on fishery species and on portions of the biota on which they depend are required. Such studies, like those of the natural and environmental requirements and tolerances of fishery populations, will require availability of adequate "laboratory animals" and hence the ability to culture a large number of single species, pure and known-history organisms for observation and experimentation. Again, rectification of these shortcomings can only be accomplished by determined efforts and investments of money and competent personnel time coupled with adequate research facilities.

Adequacy of Environmental Data

It is my belief that we know more about the fishery stocks and their numbers and availability (and are better able to predict both) than we do about the vagaries of the water environment in which they live or about their environmental requirements and tolerances. We understand even less about the interactions between climate and the water milieu and the effects on fishery stocks and their size and distribution.

The degree of weakness of environmental understanding (and control) varies according to geography and to the complexity of the system involved. We know more about freshwater (limnological) systems (i.e., ponds, lakes, streams, and rivers), less about estuaries, and least about coastal and estuarine waters. Generally more is known about such systems in the older, more sophisticated and industrialized countries and least in the newer, less developed and sophisticated ones. The United States does reasonably well by comparison with others, but even in our country knowledge of the fishery-relevant phenomena in the oceans needs much improvement--as attested by the current concerns over lack of significant knowledge of the short- and long-term effects on fishery populations of ocean dumping, heavy metals, discharges, dredge spoil disposal, treated and untreated sewage discharges, and oil and gas development into coastal and oceanic waters. Experience teaches that water quality criteria and standards are increasingly difficult to develop with confidence for estuarine, coastal, and oceanic waters in that order. Yet accurate and realistic criteria and standards are essential for effective water quality management.

For a number of years marine scientists have speculated about, and even looked for, interactions between short-, mid-, and long-term meteorological phenomena and biological systems. For example, temperature and light were considered in the case of the world-wide eel grass demise which occurred in the '30s, and attempts have been made to correlate blue crab abundance with rainfall. Many other examples can be given. The most direct and easily measured environmental phenomena, such as temperature and rainfall, have been investigated longest, and the effects of unusual shifts in the winds, such as that which presumably causes El Niño, are widely known. Obviously there are connections between weather phenomena and the conditions which affect fishery stocks and industry activities in estuarine, coastal, and oceanic waters. The problem is to understand them.

Especially difficult to comprehend are long-term or large-scale weather and oceanic phenomena, because reliable measurements have only recently been possible, and we lack long-term data to analyze. Even where meteorological data exist, only recently have analytical equipment and techniques, which would mesh such information with fishery data, become widely available. Large memory, high-speed computers have greatly aided this process. In fact, computing technology is generally ahead of the ability of fishery scientists to provide computers with reliable, long-term synoptic, large-area environmental data, and fishery population information for assimilation and analyses. Even so, computer capabilities, availability, utilization, and our measurement and modelling systems must be improved.

Adequacy of Fisheries and Fisheries Related Research and Technology

One of the questions posed for our consideration seems to concern the adequacy of the techniques of, or technology of, fisheries research. Certain remarks have been made below which apply to this subject, especially about the lack of proper assessments of the possible implications and utility of remote-sensing from instrumented aircraft, satellites, and buoys. Recommendations will be made for improvements and will not be anticipated here.

Echo-sounding (sonar) has long been widely employed to locate and evaluate stocks for catching. Fishery research also uses this technique, but tracking, identifying, and evaluating fishery stocks by active and passive accoustical methods is only now being looked into. Both technologies deserve additional efforts at development and evaluation.

Remote Sensing: Promises and Shortcomings

Availability of remote sensing from high-flying aircraft and satellites carrying sophisticated instrument packages makes it possible to observe large-scale meteorological and ocean surface phenomena (and perhaps some subsurface phenomena) across wide areas of the World Ocean. This technical ability has sparked renewed interest in fisheries meteorology and climatology and in certain aspects of fisheries oceanography. Shortcomings exist, however. Adequate "ground-truth" or "sea-truth" observations remain to be achieved. It is difficult to know what is being observed from satellites and the true significance of such observations to fishery applications, since the "underwater weather" implications are imperfectly understood. Much remains to be learned about the effects of meteorological phenomena such as dust, moisture, and other particulate matter in the atmosphere upon the observations. Much needs to be learned about the subsurface implications of remotely-sensed data. Reliable "ground-truth" (or "sea-truth") studies must be made--and quickly. We at the Virginia Institute of Marine Science (VIMS) have been trying for ten years to develop and carry out adequate "sea-truth" experiments. The scientific and technological capabilities required to do them exist. The main problems seem to be institutional and logistical. Money is clearly a problem at this time, although it hasn't been in the past!

A major difficulty with understanding ocean phenomena at sea is the lack of accurate and/or precise long-term measurements or wide-area measurements. Such observations are costly and difficult to make. And when they are made, they produce such masses of data that storage, handling, and analysis are difficult. Yet such observations must be made.

In recent years in situ "remote" buoy-supported or submerged sensors have been devised and utilized but not widely enough or in sufficient numbers. Increasing numbers of oceanographic ships bearing more scientists and instruments have been deployed, but even they have been inadequate--thus far. (Most recently continuing development and use of all of these technologies seem to be in trouble because of current budget stringencies.)

Atmospheric and ocean scientists and fisheries scientists look to remote-sensing as the key to multivariate large-scale, synoptic monitoring and observation. We also look to buoys and other in situ platforms as sites to support or deploy instrument arrays.

Until more, and more reliable, ocean and atmospheric conditions observations are available for use in carefully contrived and conducted "sea-truth" studies and in analysis and modelling and predicting of ocean phenomena--coupled with long-term ecological and populational observations--we will not understand the significance and applicability of satellite and buoy technology; and the suspicions and hopes of fishery science that these technologies will lighten their burdens and enhance understanding will go unconfirmed and unrealized. Yet these observations should be made before large reliance can be placed on these technologies and before large investments should be made in local regional remote-sensing establishments for fishery and environmental quality research and management.

Efficacy of Technology for Fisheries Research

Fisheries research depends heavily, as it always will, on being able to make direct contact with the fishery populations--the basic resource or raw product--since much necessary, useful knowledge can only be obtained (as it will be for some time to come) by counting and examining individuals of the single-species or mixed-species groups sought after by fishermen. Age, sex composition, reproductive stage, condition, species identity, and mix and even numbers can only be established by looking, counting, touching, probing, biopsying, and autopsying. Hence, direct samples of adults and young, made according to well reasoned, established, and pursued sampling plans with efficient gear, will be an essential part of fishery research for the foreseeable future.

Research sampling will involve towed nets, dredges, and other capturing gear for some time to come. Furthermore, direct samples of fishery stocks will have to be made on a regular basis in a manner compatible with current commercial fishing techniques in order to assess the utility to the industry as well as the possible effects of the industry on the stocks being fished--the interactions between the fisheries and the fisheries stocks. Hence, controlled sampling with current fishing methods will continue to be important.

Habitats and submersibles will be useful for direct in situ observations and manipulations not possible from the surface, but will likely not replace surface vessels and nets and traps in those activities which require lengthy procedures or direct handling of specimens. These special items of undersea research require special handling, and are costly to acquire and operate. Remote television and cameras are useful in observing the behavior of marine organisms in their natural habitats but cannot replace direct observations by humans using habitats, bells, tethered diving suits, submersibles, snorkels, or scuba. Of course, only the last three techniques allow relatively free movements.

In fisheries research it is often necessary to study the plankton or other small organisms on which the species in the lower end of the food chain (lower trophic levels) feed. Techniques of collection of these small plants and animals are generally satisfactory, but still involve nets or strainers towed by or suspended from surface ships which have certain limitations. Improvements should be sought.

Plankton must still be identified and counted by the trained human eye and brain using high magnifications. Manipulation, visual observation, and counting are laborious and time consuming procedures. Badly needed are techniques of manipulation, observation, and counting that shorten the time involved in landing and processing samples, that eliminate manipulation, and that ultimately eliminate the necessity for counting and identifying by humans, i.e., automated capturing, processing, automated sorting, counting, and identifying devices. It would be excellent if samples could be processed automatically and the data transferred directly to computers for processing, storage, retrieval, and analyses. Partial or complete systems to accomplish these goals would be a great boon to fishery science.

Needed to facilitate controlled experimentation is the ability to spawn, rear, and maintain laboratory controlled populations of ecologically and economically important species. The environmental requirements and tolerances of a number of species about which such knowledge is critical must be learned, as must their ability to withstand exposure to a number of man-made or mediated chemicals and processes. This is a critical lack in fishery and pollution-related environmental research. To be sure, science has been able to spawn and rear a large number of species. For example at its oceanside laboratory, VIMS has been able to cultivate over thirty (30) marine species, but they are mostly molluscan species which are relatively easy to handle and keep. It is possible to deal with certain finfishes and crustaceans for parts of their life cycle (with a few, the full life cycle); but for many, controlled spawning and development of laboratory populations of known parentage or specified characteristics and maintenance of the large numbers required for experimentation are not yet possible. This poses severe impediments to many kinds of research. More effort must be devoted to culture of marine organisms for basic research, for studies of the natural and unnatural changes and for field bioassays and feedback in pollution studies and control, and survey and monitoring.

Mentioned above were the employment of remote-sensing technology--subsurface,surface, aerial, and from space--and the great need for laboratory and field experimentation to develop new sensing technologies and to establish the significance of observations made with new and existing techniques. In many cases establishment of the significance of remotely-sensed data has been inadequate. More effort at obtaining "sea-truth" and "ground-truth" data in conjunction with appropriate satellite (space) and intermediate-level (low-, medium-, and high-altitude aircraft) data must be made.

Priority should be given these efforts, in remote sensing not only of fishery populations, but also of the atmospheric and oceanographic phenomena directly affecting or indirectly related to fishery knowledge. While there are signs that support will be given to development and placement of resource-related satellites, special efforts must be made to establish their significance and utility on a carefully controlled basis. Significant problems have been encountered in such efforts in the past.

The shopping list of needed technological and scientific programmatic efforts is so great and the resources of the scientific community so limited that determined efforts must be made to assure adequate coverage, with minimum unwanted and unnecessary duplication by those agencies and institutions who are conducting and funding much research. There are limits as to what can be accomplished along these lines for a number of reasons. Some are because of special scientific and some because of the legal mission-related requirements of the agencies themselves. Others are because of time constraints and the complexities and difficulties of dealing with the many and disparate organizational entities involved. Of course, some duplication of effort is useful to allow independent attempts for employing different techniques, personnel, and approaches; to bring about verification and reinforcement of findings and conclusions; and to provide operational redundancy, which is often the only way to increase the probabilities that positive results will be obtained within a reasonable period of time.

Of course, all phases of fishery research depend heavily upon utilization of modern statistical and analytical techniques for use in planning, conduct, and management of research. They also depend heavily upon availability and use of modern computing, data handling, interpreting, and presentation techniques. The fishery research community thus must have access to and be able to utilize the techniques of hardware and software required to deal with large volumes of data of many different types and to interpret and integrate observations from all pertinent disciplines. Adequate training in the use of the requisite software is required for all fishery and environmental scientitst. It is not possible for one individual to know or to be able to do everything in any, much less every, applicable field where limitations of time and other necessities or imperatives prevent this. An organizational personnel roster mix, replete with the required skills, is necessary.

Often research rosters are incomplete; some may even lack "critical mass." In every case lacks must be met by adequate access to persons as advisors and consultants with requisite skills. Because of the complexities and variety of the data and the analytical skills and manipulations required and the volume of information of all types (i.e., individual datum points, masses of data of one type, masses of data of many types, and semi-digested and digested data) and because of the complexities and difficulties of sampling, continuous efforts must be made on research and technological development of new hardware and software--on the technology of data acquisitions, handling and analysis specifically related to the discipline involved.

Communications Between Fishery Science and Fishery Managers

Major attention should be devoted to perfecting techniques of interpretation and presentation of data and advice to fishery management decision makers. Fishery and environmental sciences are complex, and communication of required intelligence to people outside the professional fields is difficult; yet communication is critical because, unless the decision makers understand the findings and recommendations (or have faith in their advisors--and a certain amount of faith is required anyhow), they cannot agree with them and will not, indeed cannot, employ their advice. This a vital area requiring deliberate attention from fishery scientists aided by appropriately prepared specialists from human communications areas and by appropriate communications devices. Special training, i.e., short courses for fishery managers and decision makers, may be required.

Other Research Needs

We have mentioned the need for more attention to the social sciences in fishery management and fishery research. These disciplines suffer from a number of shortcomings, among them weakness of methodology, i.e., lack of access to rigorous scientific techniques of observation and experimentation, lack of understanding of the basic psychological needs and urges of humans (i.e., fishermen, food processors and handlers, transporters, food preparers, and ultimate consumers, individually and in social groups), and other difficulties of working in and understanding sociological, economic, legal, and political areas. Obviously, elimination of such shortcomings by technological improvements will assist fishery and environmental scientists as well as fishery managers in understanding the human components of the fisheries industries and thereby will aid management. Appropriate efforts must be made to secure the needed improvements.

Organization and Management of Research Applicable to Fisheries

Research related to the fisheries is carried out by a number of governmental (state and federal), academic (public and private), and industrial (consulting and occasionally manufacturer and harvester) organizations and by academic institutions. Most of the funding required is supplied by the federal government, with states a distant second. Sources of the funds vary, with most from governmental treasuries (i.e., state and federal general funds), some from federal and state excise taxes and industry-related taxes and fees, and very little from industry revenues.

Legislative mandate often controls the organizational arrangements between management and research in the states. In some instances the legislature specifies to some degree what research and services will be done as well as what the fisheries managers may do. Often it attempts to manage in detail by remote control--usually an ineffective approach.

State research organizations are usually branches or divisions of the resource and fishery management units of their states with varying degrees of decoupling. Certain of these are wholly subservient to the management entity (of the overall organization) and some are separate, reporting directly to the overall or parent fisheries organization administrative head in a parallel arrangement as co-equals with the regulating body. In such cases the overall organizational management head may have a direct control of or significant influence over the planning, programming, and operations of the research activity. In the more decoupled arrangements, the research director and his staff have some autonomy over research activities.

In a few states the resource research unit is totally independent or is part of an academic organization, with no direct organizational ties to (not a part of) the fisheries management agency. Such organizations usually must (by statute or formal agreement) take the needs of the managers into account in their planning, programming, and operations.

Academic research units, not obligated by law or formal agreement to assist, are generally much more independent in their approach to research planning, programming, and operations than the types of state research orginizations mentioned above. In fact, they usually plan very little in an integrated way; instead, the individual faculty members--the academic scientists--do most of their own planning and management. But even they, being heavily dependent upon the state for direct or pass-through funding, or, more frequently, upon the federal apparatus, are often constrained in their approaches to research planning, programming, and operations to meet the needs and desires of the funding agencies. Federal and state fishery research support funds are usually disbursed for work directed toward the mission of management, and usually are governed by contracts resulting from proposals based upon federal requests for proposals (RFP's) which contain specifications which the research proposals must address and the researchers must accomplish. Of course, solicited proposals are selected for approval by the agency supplying the funds, presumably according to their needs and specifications.

Within the federal government most of the marine fishery-related research is carried out by the research institutions of the National Oceanic and Atmospheric Administration (NOAA/DOC), operated by the NMFS. Certain of the FWS (DOI) institutions do research related to anadromous fishes, and the FWS funds some out-of-house research, usually in state laboratories and academic institutions.

Environmental research is done by several organizations. That related to the natural marine environment and to atmospheric science which is within the mandate of NOAA is done within its own environmental laboratory system. Certain studies of the relationships between fishery stocks or populations and the environment are undertaken by the several laboratories of the NMFS. Contracts are let to state, academic, and industrial organizations for assistance in some of this work.

Pollution-related research indirectly related to the fisheries is done by NOAA (in agreement with the Environmental Protection Agency [EPA]) in-house and out-of-house, in state, academic, or industrial laboratories. Most of that which is accomplished is done within the laboratory system of EPA itself. Several of these laboratories devote themselves largely to estuarine and oceanic problems and phenomena.

It is beyond the scope of this paper to review the details of organization for and management of research in all of these agencies and institutions. We must concentrate on that for fisheries research. Worthwhile noting, however, is the fact that there are basic differences in these two features among industrial, governmental, and academic research organizations, with the last being most loosely organized and managed--less directed and less integrated. Usually individual researchers "run their own shows" in the traditional academic departments. Professionals employed by special research institutes owned by academic institutions are usually quite tightly controlled, being oriented to meeting the needs of their clients with whom they must contract to perform specific research tasks, in specified times and under certain conditions. Governmental research organizations are usually more closely integrated and directed than academic units and less so than industry, with more opportunities for basic research and more autonomy for individual scientists. Even so, they are generally able to undertake multidisciplinary research in a more organized and controlled fasion than most academic research organizations.

Governmental research organizations are more suited to the type of sustained effort needed to undertake the long-term, multidisciplinary and large-scale activities required to make meaningful studies of fishery populations and large-scale environmental phenomena. From time to time, several university groups have banded together to undertake large-scale, multidisciplinary activities. Several formal university consortia exist, but their staying-power (i.e., those without a core of regular or permanent federal funding) cannot be assessed. Most are too recent to tell how long they will last. Some are only loosely directed.

The NMFS has owned and operated a number of research laboratories for a long time. Indeed, some are among the oldest continually operating marine research institutions in the country. Several have distinguished records of solid accomplishments and worthy publications in basic marine research as well as fisheries research dating back to before the turn of the century.

The research components of the NMFS are older and probably stronger, at this point, than the management units. Indeed, except for the marine fisheries of the Territories (Alaska being one with a large federal management component until statehood was enacted) and Commonwealths and the fisheries from federal lands or controlled by treaty agreements, the federal government had not been heavily involved in actual marine fishery management until the advent of the FCMA in 1976. Prior to the passage of that Act, representatives of the NMFS publicly stated their lack of a legal mandate to manage any fisheries and fishery resources outside of the territorial waters of the United States. The states were in charge of the fisheries inside the three (3) mile territorial sea, and little management was done in the zone between the three (3) and twelve (12) mile limits (the exclusive jurisdiction zone) until the advent of the FCMA, and until it began to function. As indicated above, the several fishery management treaties to which the United States was a party involved and were served by the NMFS. Since the FCMA, the NMFS has been heavily involved in managing the marine fisheries of the FCZ. Since it advises the Secretary of Commerce, along with the councils, on management actions to take, and since it helps enforce the applicable laws and regulations, it is the management arm of the Secretary of Commerce, who is the actual action officer in FCZ fishery management activities--not the councils.

Because of the recentness of widespread management responsibilities, the research, advisory, development, and market survey services have dominated the NMFS activities, except in Alaska (and perhaps the Northwest). They remain its strongest components, though the management force is growing.

Since the establishment of NOAA, which was assigned the Bureau of Commercial Fisheries (later NMFS) from the Department of Interior, several organizational arrangements have been in effect in the NMFS. Until recently, the individual laboratories or small laboratory groups (whose site and strength were frequently functions of politics and the strengths of local fisheries and related politicians) reported to the Regional Director. The resident directors of those scientific and technological units were largely under his control. Under this arrangement, the Regional Director, who linked the Director of the NMFS with the region and with the laboratories located within regional boundaries, could and often did have strong and direct influence on the planning, programming, and operations of the research and development units. This organizational arrangement plus direct involvement in budgeting gave the Regional Director considerable control over research.

Current organization has the Regional Director (who is responsible for management-related service; advisory and enforcement activities; regional NMFS contracts; and contractual agreements with the States, Commonwealths, and Territories; and for other functions) reporting directly to the NMFS chief executive, now Assistant Administrator, Terry Leitzell. The several NMFS research and technological institutions within a particular region are organized as "centers" under a Center Director. For example, the Northeast Center consists of the Gloucester (Mass.), Woods Hole (Mass.), Narragansett (R.I.), Milford (Conn.), Sandy Hook (N.J.), and Oxford (Md.) laboratories, and the National Systematic Laboratory (D.C.), and the Atlantic Environmental Group. The Center Director also reports directly to Assistant Administrator Leitzell.

How well this organization works, especially in comparison with previous organizational arrangements, in terms of facilitating and causing the conduct of productive research (basic and applied fishery research) is hard to determine without more effort than has been possible in preparation for this discussion. It seems reasonable to assume that it could be more productive than under the former arrangement, because all of the research activities of the region are under a single administrator who is responsible for science administration only. And, by virtue of their being more isolated and insulated from the activities of the office of Regional Director, the staffs and programs of the several scientific institutions should be more secure than formerly from the vagaries and pressures of the political and social problems which the Regional Office must deal with.

One Center Director, a long-time professional, indicates that such has in fact occurred. About the possible lack of coordination in the Center meeting the research needs of the regional office that such an arrangement could invite, this Center Director says, "Obviously it behooves both the Regional Director and the Center Director to work closely together, and I think in every instance this has been the case. We usually succeed in agreeing on general priorities and on scientific research projects which need to be done to deal with the Regional Office's problem. This system has worked."

Comparing this arrangement with the past he says, "Not one of us would advocate going back to the situation in the past where we reported to the Regional Director. There is no way the Regional Director could resist the temptation to 'monkey' with a research program to make it easier for him to deal with many of his problems. As you realize, this kind of short term, *ad hoc* solution achieves little else than momentary peace for the people required to make difficult decisions which of themselves have little or nothing to do with research."

Discussions with the immediate past Regional Director and the current Regional Director reveal disagreement over whether or not the new organization is more effective than the old. The past Director says it is not, while specifying that the research centers must have some autonomy and financial support. The current Director says that though his staff (mostly older employees who worked with the old system) says that the new system is not as good as the old, he disagrees. His attitude is that the scientific and technological parts of the NMFS should be separate from the Regional Director's office--as it now is. He agrees with our Center Director.

What this Center Director says about the shortcomings of having scientific programs directly under the control of the decision-makers is true in my opinion. Some distance between the two is best retained. The lack of this distance, among other things (such as poor salaries, inadequate equipment, and lack of effective size), is a reason why many of the management-dominated state and federal research institutions are not scientifically effective and are generally held in poor scientific repute.

It does seem that research institutions and programs which fall somewhat between the research programming organizational "anarchy" of the traditional academic organization and the highly regimented arrangements of industry are most suitable to research activities like those which most fisheries and environmental research units should be expected to undertake. There are exceptions, of course.

The effectiveness of any research organization depends in large measure on the people involved. The same can be said of management agencies. A poor organization will work well if peopled by competent, cooperative professionals who wish to accomplish the job. Even the best organization will fail if it is not given competent people. After this has been said it must also be noted that, given people of equal capabilities, a well-organized system will do better than one not so well organized.

The several states of the Mid-Atlantic region and the New England (or Northeast) region and the fishery management councils involved are served by the Northeast Center and by the Northeast Regional Office of the NMFS, as well as by their own state and academic organizations. The South Atlantic and Gulf Coast States and regional councils are served by the Southeast Center and Regional Office and the research institutions within their borders. While there are (and always will be) complaints from the managers, the decision-makers, that they are not being properly served by the scientific community and their scientific advisory committees, there is little reason to believe that it is the organizational arrangement for research that is at fault! It has been my experience that both the Northeast Regional Office and the Northeast Center are conscious of the needs of the councils and the states, and are reasonably responsive in their attempts to meet them. I am told that the Northwest Center has been extremely cooperative with management. It can safely be said that the organization for research management does not adversely affect the management capabilities of the states or the councils. It also can be said that a more effective arrangement could be made to assure that FCMA council research needs are considered in the programming of Center activities. A more formal and direct arrangement than now exists between the councils and their staffs and the regional research centers would be useful, even though the councils frequently have more sound advice than they can effectively use!

The regional council Scientific and Statistical Committee route is not necessarily a good one to provide such interactions since effective continuous two-way communications between the councils and council staffs and the S & S Committees frequently does not occur. My experience as a member and even a chairman of such an advisory group has been that S & S Committees seem often to be "window-dressing." I would suggest a new, different arrangement.

However, if new organizational mechanisms for communications between the regional research centers and the councils are to be arranged, care must be taken in selection of the membership. The technical members must be suited to their roles as communicators, as should those from management's side. Often council members and possibly even key staff members are not scientifically inclined or even sympathetic to science. From time to time, council members have been chosen from among the scientific community in the region, and, where this has happened, better communications with the scientific community have occurred. This practice should be continued in selection of council members.

Obviously the regional office could serve as a nexus between center and councils, but a regular and direct route of contact and interaction, especially at the time that center research and survey activities are being planned and programmed, could improve the efficiency of the research programs and of the advisory services of the centers. The same can be said of interactions among the councils and the Sea Grant Program network and of the major state and academic organizations.

Better communications can lead to better research, and managers should be more closely involved in programming; but the ultimate interpretations and decisions of research needs must be left to the research administrators and scientists themselves.

SUMMARY

I have noted the need for increased knowledge of fishery stocks and their environmental interactions, requirements, and tolerances, and of the fisheries which depend upon these stocks. I have also noted the need for improvement of organization and technology and investment to bring about this increased knowledge. Further, the need for improved ability to interpret fishery knowledge and present it to fishery managers in ways intelligible and useful to them has been noted. All of these needs and requirements are real--but they will be of little avail if fishery management units ignore or are unable to utilize the knowledge and advice that is (already) available to them. More services and advice are available than are now being effectively utilized. Immediate attention must be given to the social and political engineering efforts necessary to improve this situation. Scientific and technological knowledge and advice is of little avail unless it is employed.

This is not to indicate that the improvements in knowledge, skills, and manipulative abilities of fishery science cannot or should not be made. Indeed they can, and efforts to do so should not be delayed. Some areas requiring improvement have been identified along with general recommendations for doing so. Because of the long-term nature of some of the natural phenomena involved, their inherent complexities and difficulties, and the lengthy scientific activities required to develop new technologies, improved organization, and knowledge, it is imperative that the effort not be delayed!

A WARNING AND A PLEA

Consideration has been given to the status of fishery research and the technological and organizational weaknesses in fishery science. In some instances it has become clear that fishery science could be markedly improved merely by greater efforts, i.e., investments of money, scientific time, and equipment, in one scientific area or another; but today there is cause for concern that rising costs and negative budget pressures will bring about reductions rather than increases. Indeed, it is already happening! For example, NOAA and other research organizations are either laying up or facing lay-ups of ships due to sky-rocketing fuel and maintenance costs; NMFS is talking of reducing aqua-cultural programs, socioeconomic research, and other efforts.

Fishery managers, the fishing industry, and the fishery science and environmental science communities must make every effort to keep such reductions to a minimum. The entire fishery science and management effort will suffer if survey, monitoring, and research activities are markedly reduced because of lack of ship time. Vessels now offer the only feasible and reliable means of conducting these necessary activities. Later it may be possible to reduce dependence upon them, but for now it is not! We must jointly struggle to keep appropriations at a sufficient level to maintain current levels of scientific activity, even to improve them.

RESEARCH NEEDS FOR MULTISPECIES FISHERIES

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In the ecological sense, all fisheries must be considered multispecies. Even when a single species can be caught, there are few populations that are not linked by the web of energy relations. This fact has, of course, been recognized for a good many years, but McHugh (1959) was the first I know of to voice explicitly the need to consider it in management strategy.

In practice, however, management of fisheries has followed the development of models which relate fishing mortality and yields. Those that have had any effects were single-species models, and were based largely on data from major fisheries with a single sought-after species. The consequence of this development has been a lack of the more comprehensive data required to develop empirical multispecies models; even theoretical development has been hindered by the lack of data to test models.

The topic of multispecies fisheries can be considered in two parts. First is the operational fisheries aspect which is a practical matter of measuring and controlling the allocation of fishing mortality over the resource components. Secondly, there is the ecological aspect of the allocation of energy among the resource conponents. We need to know what the total productivity is and how this might be partitioned among the elements. This information is required in order to assess effects of fishing in the first instance, and to provide advice on the possibilities and effects of altering the pattern of allocations of fishing mortality.

General Considerations

The assessment of effects of fishing and the determination of potential yields and management strategy can be built from the bottom up or top down. Simply stated, we are considering the following relationship:

$$T_p = \int {*}I_p, \text{ and} \tag{1}$$

$$T_y = \int {*}I_y, \text{ where} \tag{2}$$

T_p = total (fish) productivity,
I_p = individual "stock" productivity,
T_y, I_y = yields from this productivity, and
$*$ = convolution.

We can start on either side of these relations, presuming that either approach will produce the same relation. The equations, however, are not necessarily invertible. The relationship is an identity by definition, but the methods of assessment of productivity and yields can produce a less than or greater than relationship.

The left-hand side represents the top down or biomass approach. Only very large componenets, e.g., "all finfish" or "all epibenthos," are considered in aggregate. This applies both to management and to research. One ignores labels and quality, and deals only with quantity. This approach may well be termed suboptimal in character, but both management and research should perhaps start from first principles. The right-hand side of Equation 1 or 2 is the bottom up or multispecies approach. It is concerned with individual "stocks," which may include more than one species or population, but both management and research proceed by combining differentiated elements. Labels and quality are important. This approach is optimal in that each element of the system is identified, its productivity measured, dependent relations between elements determined, and fishing mortality allocated among them to match or change the relations. This is, of course, a very sophisticated stage of research and management.

The history of management and research reflects the latter approach in the sense that each stock was treated independently, but the interrelations were not determined and were generally ignored. The inability to allocate fishing mortality by managing the components independently, and the lack of knowledge about interspecies effects are ultimately impediments that management must overcome if it is to succeed.

The Northwest Atlantic--A Case Study

The Northwest Atlantic exhibited the most intensely fished and studied multispecies fisheries in the world. By the 1970s, most of the major fish stocks were being fished, and fishing vessel capacity was increasing far beyond the capacity of fish stocks to support it. Management in the Northwest Atlantic, under ICNAF, is the only example to date of explicitly applying both biomass and multispecies principles in the control of fishing activities.

The Northwest Atlantic fisheries have been established and observed for centuries. Biological investigations have been conducted since the late 1800s, becoming more extensive since 1930. Thus, the amount and quality of available data is much greater than for any other area. The trends in fisheries, noted because of the extensive records, have generated studies of the dynamics of stocks. Because of the fact that most commercial interest was focused on the larger fisheries based on a few species (haddock, Atlantic herring, Atlantic cod, etc.), the investigations were originally directed toward only a few components, and management has generally followed the same course. Expansion of fisheries after World War II was achieved by mid-range and long-distance fleets, primarily from Europe and the Socialist Bloc countries. At first, these fleets sought new populations of the traditional species, then additional populations of different species which were large enough and concentrated enough to meet the fleets' logistic requirements. The final step, after the best options were taken, was to fish large areas for a multitude of species in order to keep the fleets going. It wasn't really until the latter stage, where the importance shifted from the single-targeted species, that landings (as opposed to total catch) were more completely reported, and that multispecies management became recognized as a necessity. It became literally impossible to sort out the maze of exemptions under mesh and quota regulations caused by the growing importance of formerly nontargeted, nonlanded species.

The first step was merely to document the mortality estimates applied to the various stock components. Documentation was necessary just to force a recognition that the traditional concepts were not adequate to control and allocate fishing mortality. This documentation was first conducted by ICNAF in the early 1970s (Grosslein, 1972; ICNAF, 1973).

The problem of estimating total fishing mortality and its distribution over the entire complex of thirty or so of the important species was solved by identifying major fisheries stocks and areas fished, from which mortality estimates were available. Fishing mortality on other than the major species-stock was estimated by associated catch ratios (Table 1). These calculations demonstrated that total mortality was 138% of that estimated by the consideration of major stock fisheries only.

The second step was to estimate the relationship between yield and fishing mortality for the total biomass. An approximation of total potential yield was obtained by applying very basic trophodynamics models (Au, 1973). Although this technique is useful to establish general guidelines for potential yields, the results are very sensitive to the choice of elements included in the trophic levels and the energy-exchange coefficients.

A more empirical approach was employed by applying the generalized productivity models (e.g., Schaefer) to the total catch and effort (Brown et al., 1976). This provided an estimate of where current effort stood in relation to maximum potential yield, and also permitted the options for both catch and effort regulation to control mortality (Figure 1). A comprehensive analysis of standardizing effort among various fleets was involved.

Both types of control were formulated for ICNAF. A total-effort control scheme was proposed (ICNAF, 1973a, b), but was not adopted because of the uncertainty of its effects on the economics and operation of fisheries. A total-yield regulation was adopted in 1973 (ICNAF, 1974). The problem then became one of finding a scheme to determine the catch alternatives which would achieve the goals of fixing total mortality and allocating the proportionally desired mortalities to the individual stock components by species quotas. These were accomplished by using a linear statistical programming model with total and stock-component constraints (Brown et al., 1973). An initial solution is shown in Figure 2.

This whole process involved a rather extensive debate about the relation between total productivity and its estimation from summing the individually estimated component productivity. It was concluded that the total was less than that estimated by adding individual components as routinely estimated (Table 2). Thus, it was concluded that the methods of estimation did bias the right side of Equation 2 such that an inequality was introduced. Observations of the Northwest and Northeast Atlantic fisheries do indicate a general principle that the total yield is much more stable than any of the major species components of the ecosystem (Figures 3, 4). This has some obvious implications for management's concerns about stability.

Review of Multispecies Models and Data Requirements

Most multispecies modeling, until the present time, has been useful chiefly to illustrate the concepts and consequences of fisheries management. Outside the Northwest Atlantic very little serious consideration of actual application has taken place. In the last year or two, however, more serious consideration has been promoted within the U.S. and in ICES. Grosslein et al. (1979) reviewed the recent program of research of the Northeast Fisheries Center (NEFC) directed toward ecosystem modeling and management. Ursin (1979) has reviewed multispecies fish stock and yield assessment in ICES, particularly development related to the northeast fisheries.

All the models deal essentially with the relationship between prey and predator. The more recent developments concentrate on natural mortality as the internal partitioning of energy, with fishing mortality as a driving force that changes the stock size of a species whose predation influences the natural mortality of the prey species. It is a characteristic of all the models that the predator man is treated as an exogenous variable. Thus, the implication is that management, through the use of these models, will provide the necessary feedback between the ecosystem and man's effects. This approach tends to eliminate thought about how to build in more direct and automatic feedback loops which will be necessary because of the complexity and difficulty of modeling the ecosystem (Hennemuth, 1979).

Trophodynamic models have been used to provide an overall estimate of the biomass available to fisheries, and its potential harvest. This methodology has been frequently used in the past to provide a measure of large-area potential yields. An illustration of this familiar approach is presented by Ricker (1979) and shown in Figure 5. More recently, studies have dealt with more accurate tracing of the pathways in the energy web. Some of these are illustrated in Figures 6 (Walsh, 1980), 7, and 8 (Cohen et al., 1979). These models have the virtue of dealing with the "fishing-down-the-food-chain" problem which has seriously confused the perception of potential yields in the past.

This type of assessment can be provided without fishery statistics--a virtue when fisheries in an area are not well documented or are just developing (e.g., Antarctica). Remote sensing may be used to rapidly obtain rough estimates of primary (and perhaps secondary) production. An intensive one-year research vessel activity could provide some useful initial estimates of primary and secondary production and implications for potential fish yield. However, definitions of the pathways, the rates of interchange, and the variability of these processes require more extensive survey work over several years. Experimental work is also required to refine the coefficients of energy exchange. While the total primary production may be used as a starting point, the quality, i.e., the species composition reflecting different particle sizes, may affect the utilization and the quality of the end products. Grosslein et al. (1979) has described the requirements for the Northwest Atlantic area as an example of the research program needs for this type of trophodynamic model.

The other major class of models treats the interaction primarily within the fishery biomass. Many of the models tend to be extensions of those which have been developed for single-species population analysis (Lotka-Volte, Beverton-Holt, cohort or virtual population analysis [VPA]). The latter two are constructed by differentiating the causes of the natural mortality and specifically identified predation. Treating the whole multidimensional array of such interactions becomes a very difficult bookkeeping operation. The realistic analysis at the present time tends to estimate the effect on its prey species of the changes in a single predator--or perhaps a few predators (Figure 9). Ursin (1979) has reviewed such models.

The data requirements are quite severe, for the multispecies assessment models in that size and age composition of the various populations have to be estimated over a period of many years. The predator-prey interactions are based largely on evaluating diet composition and estimating food consumption and the rate at which these factors cause energy exchange between components.

Essentially these models are very similar in the way prey is distributed among predators. A suitability index, Gij, of each prey-species age group j for each predator age group i, weighted by the relative abundance of that prey in terms of total prey abundance, is used to estimate the actual amount of that prey consumed by the predator group. As shown by Sparre (1979), empirical food-composition data can be translated in an estimate of the suitability index by means of an iterative procedure. Information on each predator's diet composition therefore represents an essential input requirement of these models. In the models developed by Anderson and Ursin (1977) and by Helgason and Gislason (1979), an overall suitability index is formulated as the result of two components. A prey-size/preference index is derived from a preferred prey-size/predator-size ratio; a vulnerability index is related to the availability of a species as prey for a predator. This more complex formulation has the advantage that the preference index may be estimated from stomach analysis of samples which do not necessarily have to represent a random sample of the population, whereas the vulnerability index can be approximated in connection with knowledge of the general biology of the species involved.

In all these models the suitability index should be tested against or calculated from an estimate of the total food composition of each predator age group in a particular year. In order not to be biased by seasonal or geographical variation in food composition, an empirical estimate of the average annual food composition for a population by age groups as a whole is essential, and this makes high demands on the sampling scheme involved. The almost complete lack of reliable estimates of the dietary composition for all the major fish predators included in any species interaction assessment exercise is a major gulf which has to be bridged in order to test these models.

Collection of data on diet composition of the major predators should be considered the primary objective of any large-scale stomach analysis program, and is absolutely necessary to allow progress in multispecies assessment techniques.

Data on diet composition can be converted into estimates of the annual food requirements in two ways: (1) from information on the amount of food in stomachs and digestion rates, and (2) from consideration of energy requirements.

Food preferences (in terms of the suitability coefficient G) can also be estimated in two ways: (1) empirically, using a set of stomach content observations and population numbers calculated in species interaction cohort analysis (Sparre, 1979), or (2) analytically, by investigating the choice of food and estimating prey size preferences (coefficient G). The product of these coefficients gives the suitability coefficient G (Appendix II) with respect to food preference.

It must be pointed out that carrying out large-scale surveys to assess food consumption and its composition will make considerable demands on research vessel time and scientific manpower, particularly in processing the stomach data. There are two basic requirements: information on total food consumption and its composition within each area of concern, and an index of relative abundance for each predator category between areas. Although the first of these could be at least partially obtained by appropriate sampling of commercial catches for stomach contents, the combined requirements are better met by research vessel surveys carried out throughout the year. However, it should be stressed that once adequate sampling has been achieved to give reliable estimates of annual food requirements and composition of the major predatory species, repeated sampling will not be required in each subsequent year. In order to test the assumption of a constant-food-suitability index, sampling should be repeated, although not necessarily immediately, especially when there is a major change in the availability of the prey species.

The essential information to be collected from this extensive stomach-contents analysis includes the size of the predator, the number and sizes (weight) of the prey animals, and the total weight of the stomach contents. This raises the question of the level of identification and grouping of the prey. Ideally, stomach contents should be identified to species and, where applicable, to life stages, and should be measured and weighed individually.

Ultimately, it is paramount to the credibility of species-interaction assessments that prey consumed are correctly assigned to age groups of prey as well as of predator. Therefore, lengths of prey species should be recorded whenever the state of digestion allows. The length distributions can at a later stage be converted into age groups by means of appropriate age-length keys. An alternative would be to identify otoliths of predators as well as of the prey in the stomachs.

If consumption estimates are based on stomach contents data rather than simply energetic considerations it is necessary to translate the average weight of stomach contents into estimates of food intake based on the rate of digestion. Even though the principles of gut evacuation in fish are reasonably well understood, little of the published information deals with commercially important marine fish. As a consequence, there is a strong need for extensive digestion experiments which specifically address the problems of differential digestion for different prey types, prey sizes, and meal size, and which are directly relevant to the type of food spectrum observed under normal conditions.

General Considerations for Management

Management tends to use implications of the models to solve political allocation problems, for example, to calculate the consequences of F on a single stock in relation to a particular set of prey species, which themselves form the basis of desired fisheries. Multispecies management probably cannot start by using one-on-one relationships. A perusal of the exploratory multispecies models provides some clues as to how the necessary feedback might be included. A few models provide for concepts and inferences that furnish useful guidelines for general policy and strategy development in management. One of these is by Smith (1975). At the very least, regulatory measures should be robust with respect to errors in assumptions about effects. The following points provide some general guidance to managers.

1. Permit fishing mortality only as a passive force. This could be

achieved by the use of passive gear such as set lines, traps, set nets, etc. The prime criterion is that a constant exploitation rate be generated so that as density (biomass) decreases, the catch also decreases, and vice versa. This same effect can be achieved for active gear by regulating fishing effort.

2. Minimize perturbation by removing species in proportion to their biomass. This procedure requires either the use of nonselective gear, or the control of gear by selective factors. A less efficient but similar result could by obtained by prohibition of discarding. This would tend to constrain severe selective removals (fish caught in the net have low survival, thus discards are a loss to the system) by tending to prevent filling up boats with a single species. This measure is related to exerting a "white noise" perturbation which, for some models of the ecosystem, creates less extreme perturbation. The alternative of specific removals is a good strategy, in terms of minimizing effects, only if the fishing mortality is placed on species which have a small interaction with other species. If this is known, it could be used to minimize vulnerability of the system to the fishery by permitting directed fisheries only on such species. Fishing mortality should not, however, be overly directed to species with long time-reactions, i.e., late maturation, slow growth.

3. Direct fishing mortality more on ecosystems with higher spatial heterogeneity. This procedure may be a matter of geographical, or even seasonal, definition of management units.

4. Regulate fishing mortality to the smallest possible unit (area of subpopulations).

5. Reduce the number of differently regulated fishing units in order to deal with a single homogeneous disturbance. In fishing, multiple regulated fisheries may be perverse enough to combine and drive the system more rapidly to an undesirable state. In combination with Measure 2 above, a regulation of the total of all species catch would tend to allow this.

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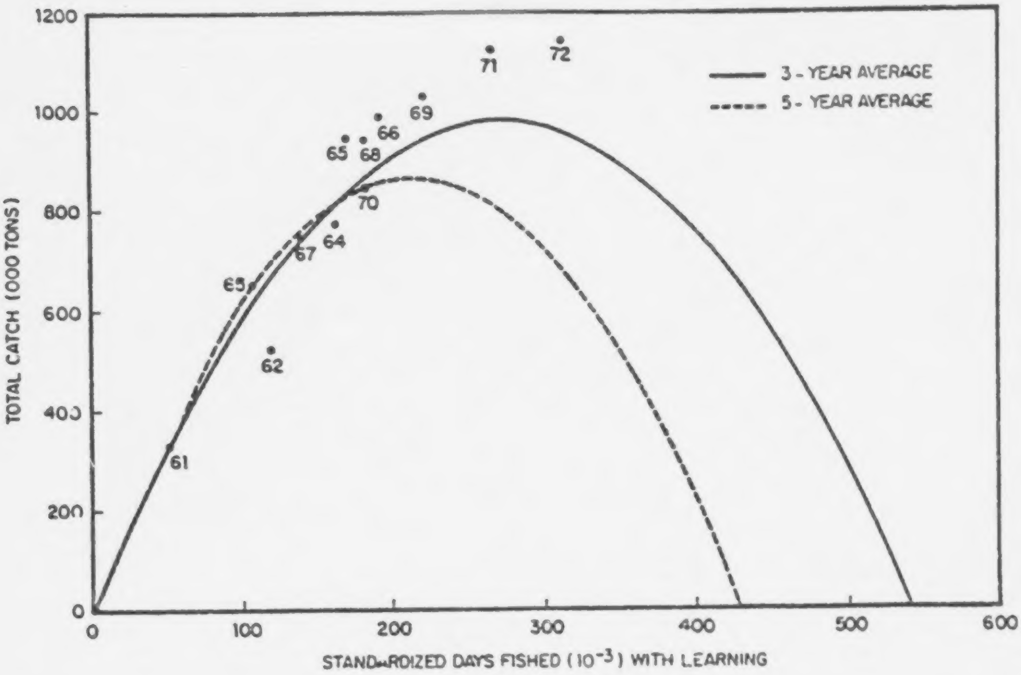


Figure 1. Estimated yield of finfish biomass off New England.

FINFISH + SQUID

SUBAREA 5 + 6 · 1976 TAC's

SPECIES (FIRST TIER)	TAC
COD	43
HADDOCK	6
SILVER HAKE	103
RED HAKE	42
HERRING	(69)
MACKEREL	254
SQUID	74
POLLOCK	17
YELLOWTAIL FLOUNDER	20
REDFISH	17
OTHER FLOUNDER	20
OTHER FISH	150
SPECIES TOTAL	816

ALL SPECIES (SECOND TIER)	650

Figure 2. Two-tier system of quota regulation generated by linear programming model.

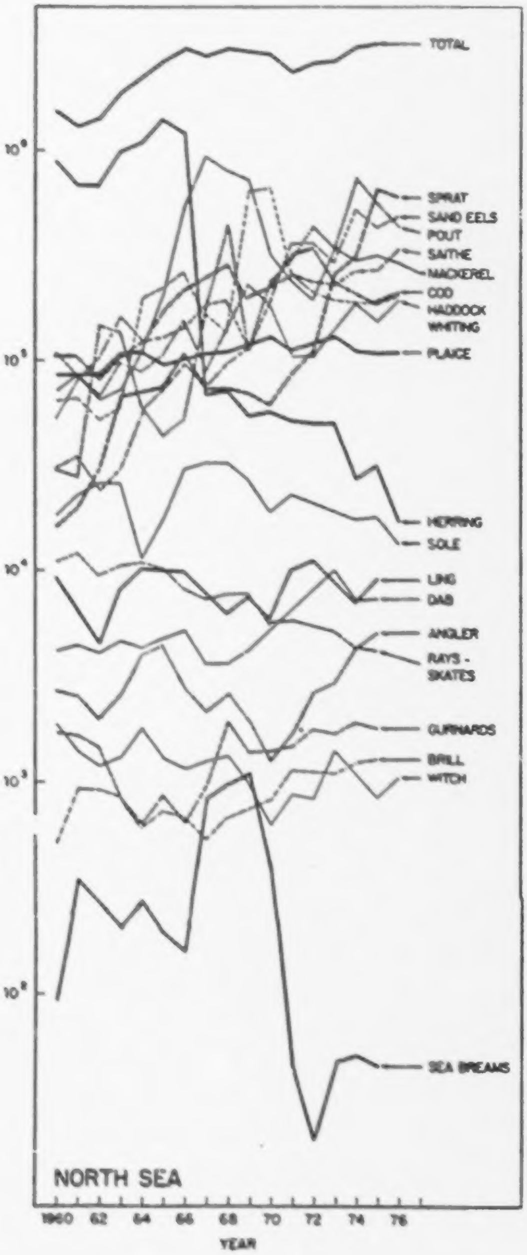


Figure 3. Total and major species yields in the North Sea.

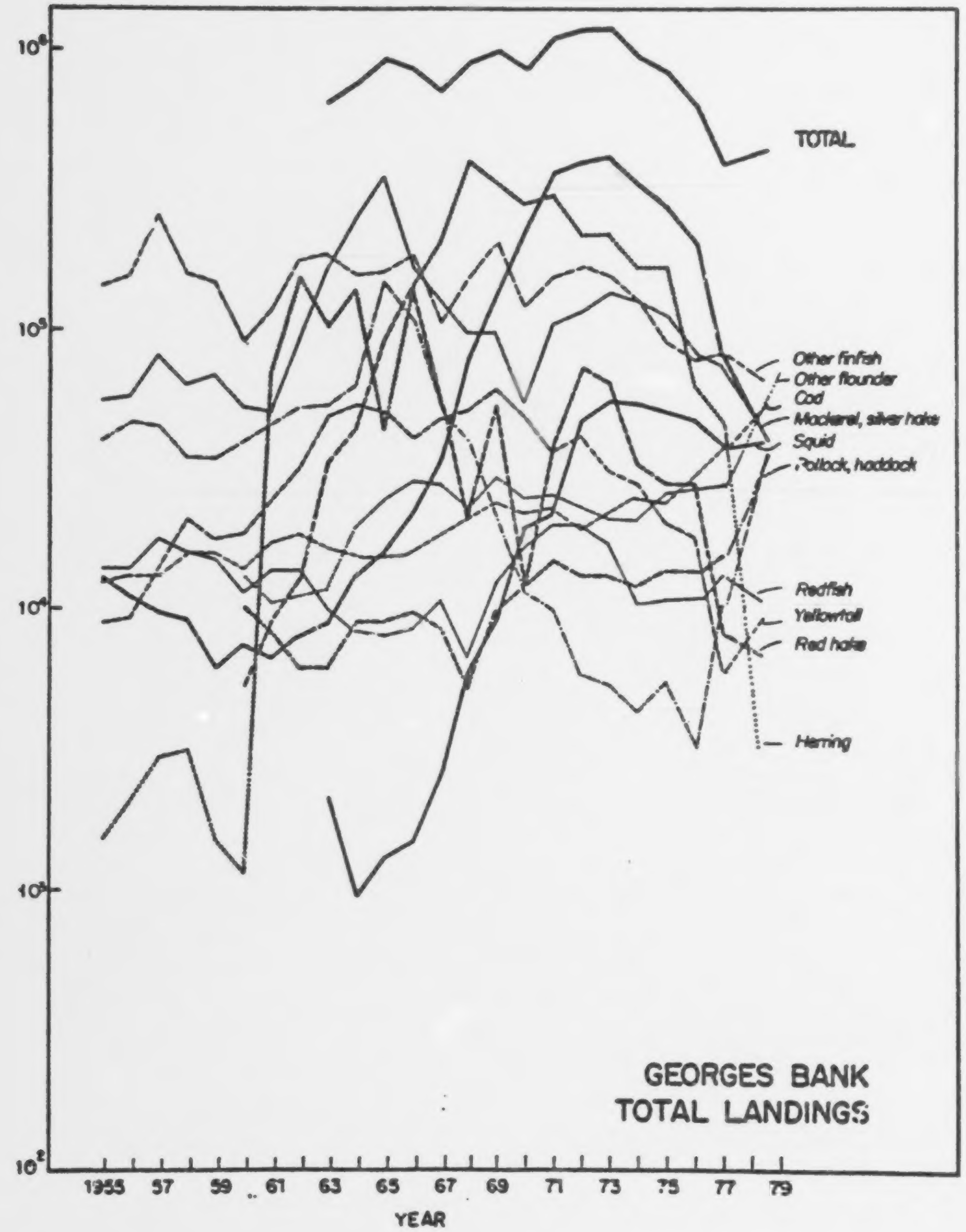


Figure 4. Total and major species yields from Georges Bank.

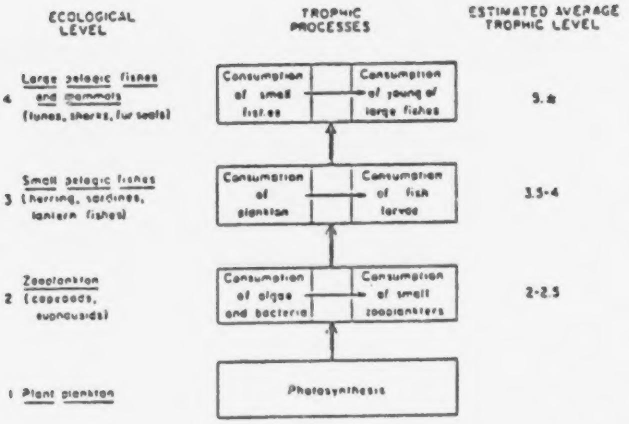
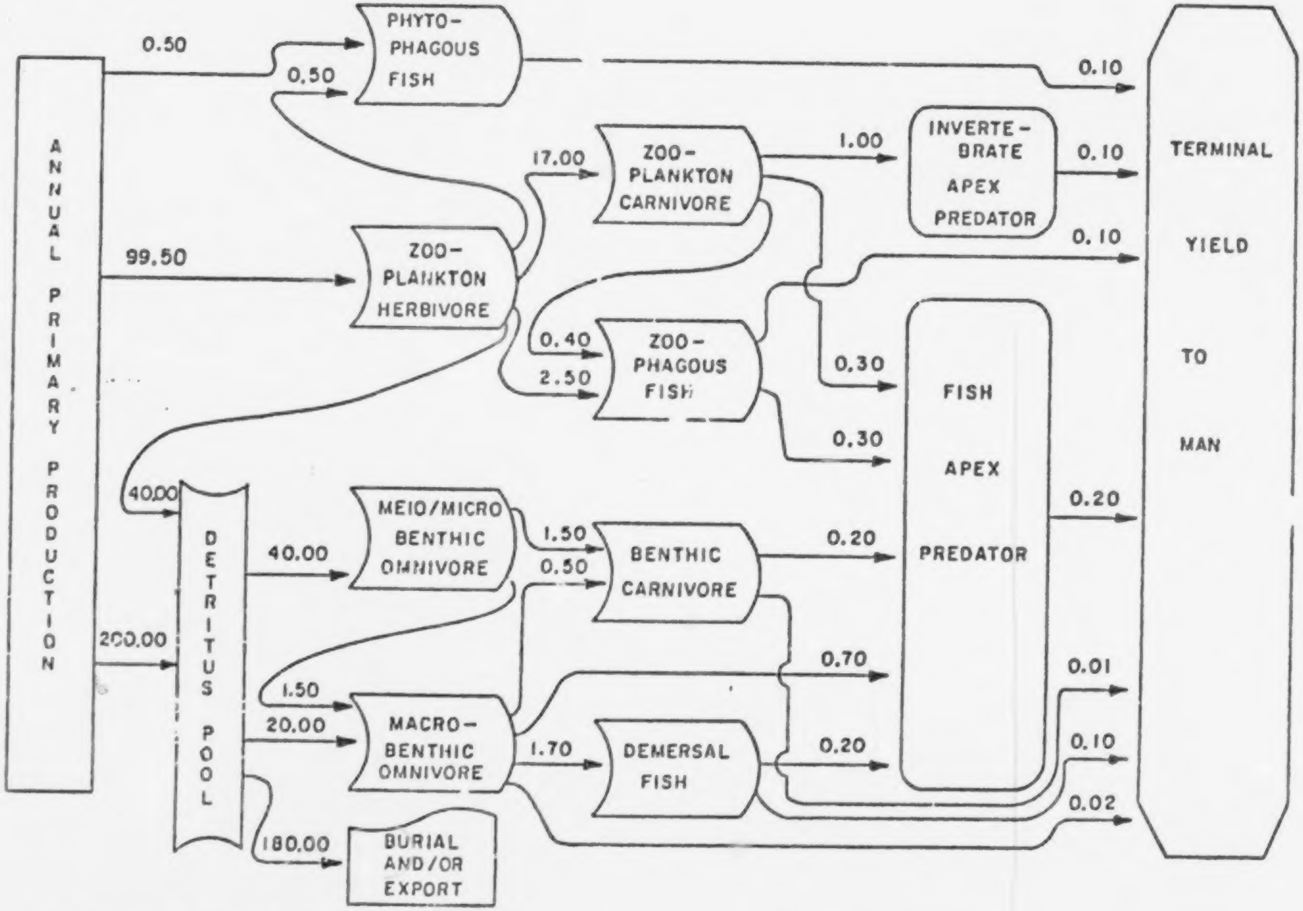

ECOLOGICAL LEVEL
TROPHIC PROCESSES
ESTIMATED AVERAGE TROPHIC LEVEL
4 Large pelagic fishes and mammals (tunas, sharks, fur seals)
Consumption of small fishes
Consumption of young of large fishes
5.±
3 Small pelagic fishes (herring, sardines, lantern fishes)
Consumption of plankton
Consumption of fish larvae
3.5-4
2 Zooplankton (copepods, euphausids)
Consumption of algae and bacteria
Consumption of small zooplankters
2-2.5
1 Plant plankton
Photosynthesis

Figure 5. Trophodynamic estimate of world marine catch by Ricker 1969.


ANNUAL PRIMARY PRODUCTION
0.50
99.50
200.00
40.00
PHYTO-PHAGOUS FISH
0.50
ZOO-PLANKTON HERBIVORE
17.00
ZOO-PLANKTON CARNIVORE
1.00
INVERTE-BRATE APEX PREDATOR
0.10
0.10
0.10
0.40
2.50
ZOO-PHAGOUS FISH
0.30
0.30
FISH APEX PREDATOR
0.20
DETRITUS POOL
40.00
MEIO/MICRO BENTHIC OMNIVORE
1.50
0.50
BENTHIC CARNIVORE
0.20
0.70
1.50
20.00
MACRO-BENTHIC OMNIVORE
1.70
DEMERSAL FISH
0.20
0.01
0.10
0.02
180.00
BURIAL AND/OR EXPORT
TERMINAL YIELD TO MAN

A CARBON BUDGET ($g\ C\ m^{-2} yr^{-1}$) OF YIELD TO MAN ON THE NORTHEAST CONTINENTAL SHELF

Figure 6

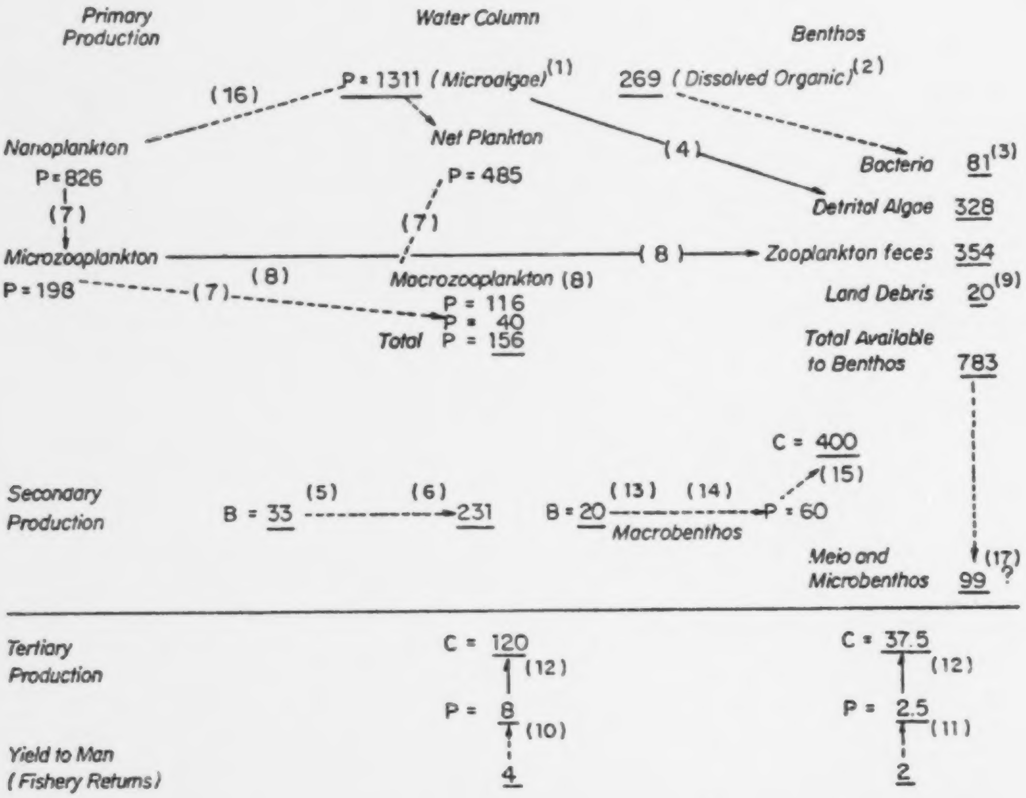

Primary Production
Water Column
Benthos
P = 1311 (Microalgae)(1)
269 (Dissolved Organic)(2)
(16)
Nanoplankton
P = 826
(7)
Net Plankton
P = 485
(4)
Bacteria 81(3)
Detrital Algae 328
(7)
Microzooplankton
(8)
Zooplankton feces 354
P = 198
(7)
(8)
Macrozooplankton (8)
P = 116
P = 40
Total P = 156
Land Debris 20(9)
Total Available to Benthos 783
C = 400
(15)
Secondary Production
B = 33
(5)
(6)
231
B = 20
(13)
(14)
P = 60
Macrobenthos
Meio and Microbenthos 99
(17) ?
Tertiary Production
C = 120
(12)
P = 8
(10)
C = 37.5
(12)
P = 2.5
(11)
Yield to Man (Fishery Returns)
4
2

Figure 7. Energy budget for the North Sea. In the above figure, energy flow between trophic levels is linked by arrows, but the direction of the arrow represents the logical derivation of the values given, not the direction of energy flow, which is always from top to bottom of the page. The double underlined values are based on observations, the continuous interconnecting lines are steps based on observed relationships, while the dotted interconnecting lines indicate more speculative relationships. Numbers in parentheses explain the relations observed or assumptions made. See next page.

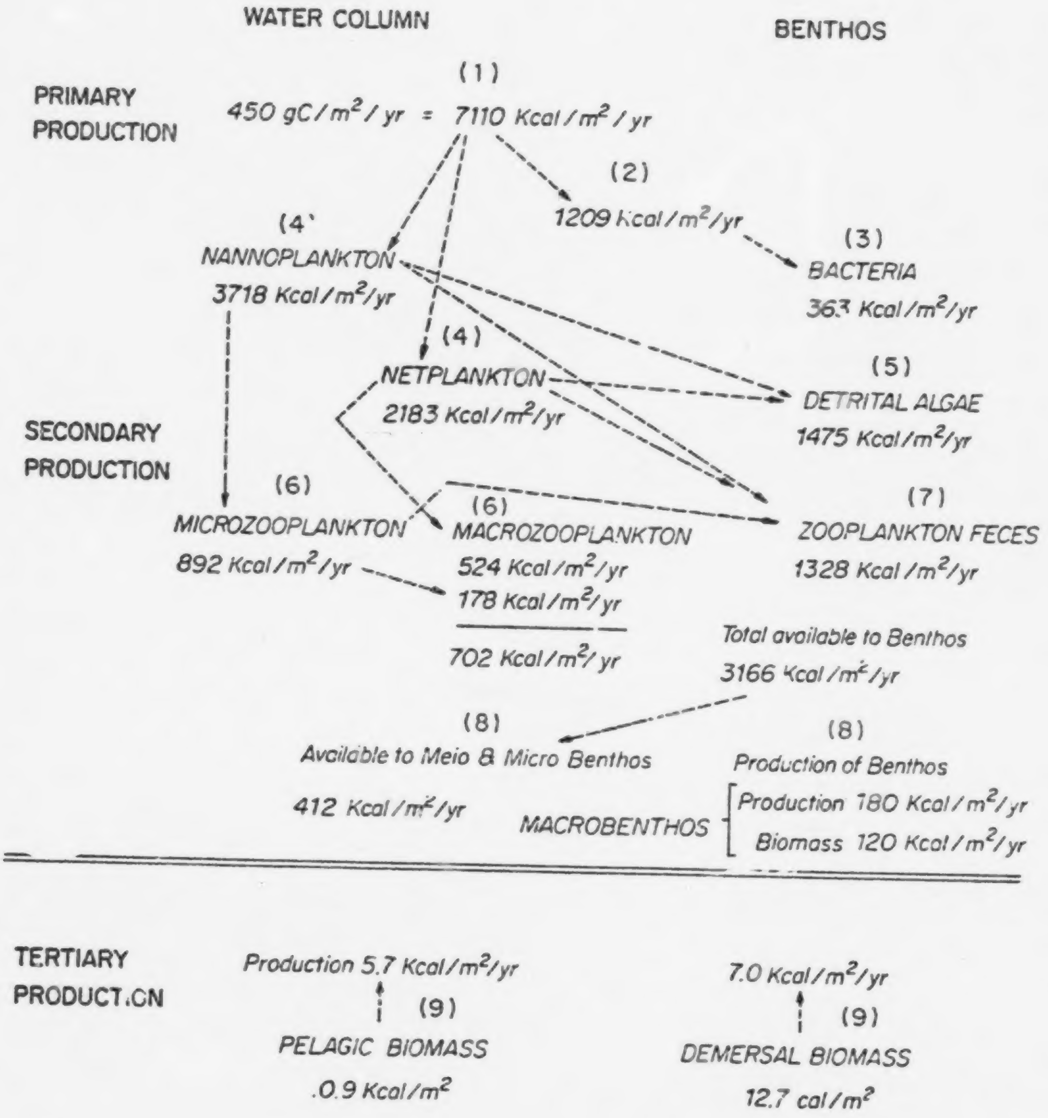

WATER COLUMN
BENTHOS
PRIMARY PRODUCTION
(1)
450 gC/m²/yr = 7110 Kcal/m²/yr
(2)
1209 Kcal/m²/yr
(3)
BACTERIA
363 Kcal/m²/yr
(4)
NANNOPLANKTON
3718 Kcal/m²/yr
(4)
NETPLANKTON
2183 Kcal/m²/yr
(5)
DETRITAL ALGAE
1475 Kcal/m²/yr
SECONDARY PRODUCTION
(6)
MICROZOOPLANKTON
892 Kcal/m²/yr
(6)
MACROZOOPLANKTON
524 Kcal/m²/yr
178 Kcal/m²/yr
702 Kcal/m²/yr
(7)
ZOOPLANKTON FECES
1328 Kcal/m²/yr
Total available to Benthos
3166 Kcal/m²/yr
(8)
Available to Meio & Micro Benthos
412 Kcal/m²/yr
(8)
Production of Benthos
MACROBENTHOS
Production 180 Kcal/m²/yr
Biomass 120 Kcal/m²/yr
TERTIARY PRODUCTION
Production 5.7 Kcal/m²/yr
(9)
PELAGIC BIOMASS
.0.9 Kcal/m²
7.0 Kcal/m²/yr
(9)
DEMERSAL BIOMASS
12.7 cal/m²

Figure 8. Energy budget for Georges Bank. Energy flow between trophic levels is linked by arrows, but the direction of the arrow represents the logical derivation of the values given, not the direction of energy flow which is always downward. Numbers in parentheses explain the logical basis of calculations. See next page.

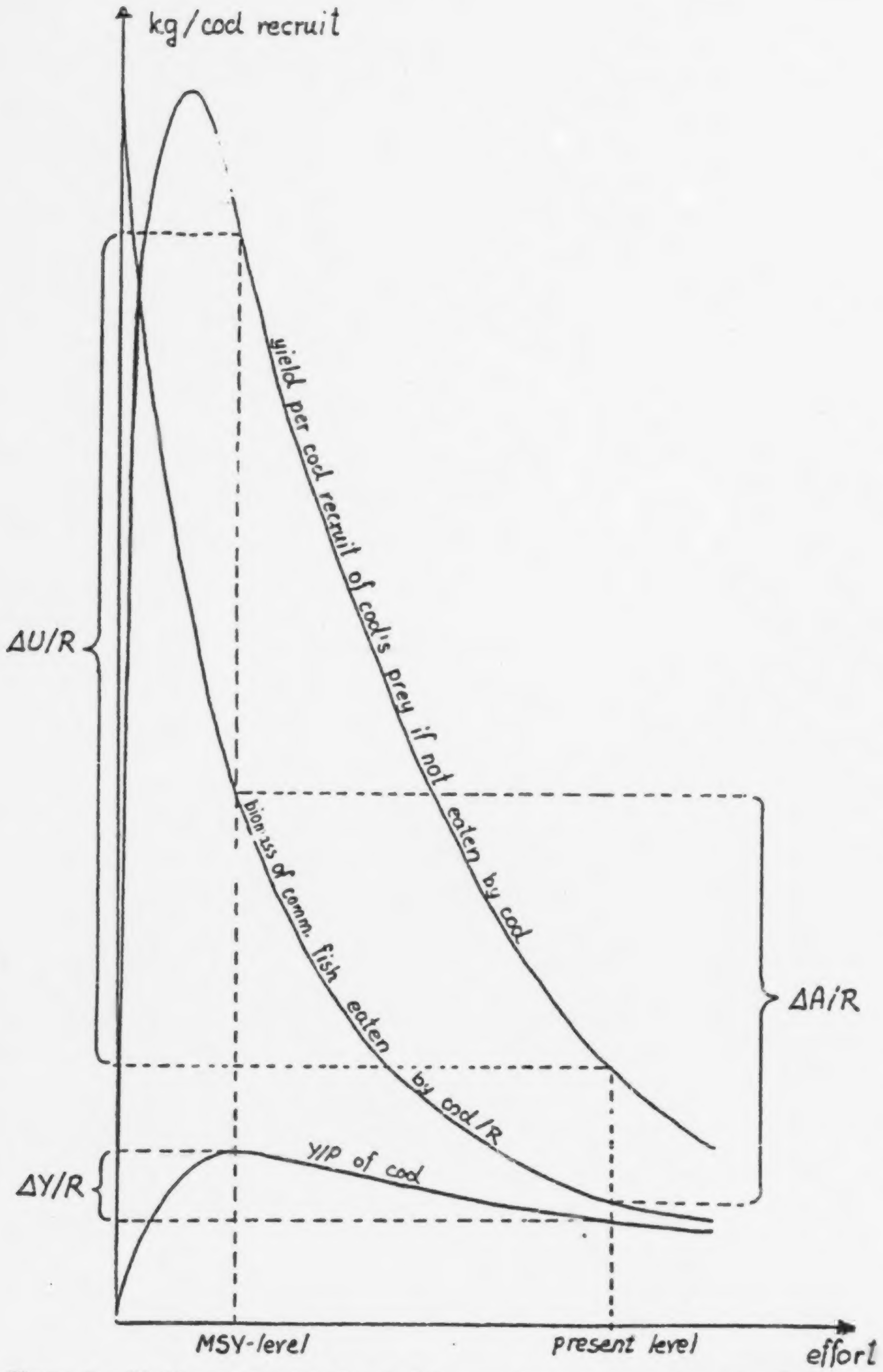


Figure 9. Yield per recruit of cod with prey interactions. From Sparre 1979.

Source	Max. Sust. Level: Yield ('000 tons)	Max. Sust. Level: Standardized effort	Ratio of MSY to 1971 catch	Standardized effort at MSY relative to standard effort for 1971
Catch/effort yield curve	843	151[2]	843/1066 = 0.79	151/191 = 0.78
Yield per recruit curve	855	120[2]	855/1066 = 0.80	120/155 = 0.77
Sums of species assessments	1202[1]	215[2]	1202/1066 = 1.13	215/287 = 0.75
Primary productivity	1000	-	1000/1066 = 0.94	-

[1] Includes 600 for herring and mackerel, and an allowance of 100 for other pelagics and other fish (see Table 9).

[2] These estimates cannot be directly compared with each other.

b) Yield-per-recruit assessment

Advice to the Commission is often given on the basis of consideration of yield-per-recruit. In particular, the Report of the Assessments Subcommittee in 1972 (*Redbook* 1972, Part I, p. 15-42) indicates that two points of reference are available: F_{max} and $F_{0.1}$, the latter being related to economic optimization. In Table 4 the yield and effort are related to the mid-point of these two values, which is probably very near the maximum sustainable yield. The curve is shown in Fig. 3.

Table 1. Estimation of fishing mortality generated as by-catch. From ICNAF 1973.

SUPPLEMENT

Supp. Table 1. Estimated days fished for main species in SA 5 in 1971, standardized to US OTSI 0-50 tonnage class.

Main species sought	Stand. days fished[1]	Species Caught										% f as by-catch[3]
		Cod	Had	Red	SH	Flo	OG	Her	OP	OF	Total	
Cod	2,826	2,826	2,279	34	130	378	483	6	0	3	6,137	54.0
Had	4,475	1,629	4,475	76	9	828	1,307	0	0	0	8,324	46.2
Red	1,478	238	3.0	1,478	86	180	452	13	0	1	2,758	46.4
SH	28,697	488	803	115	28,697	2,124	7,920	3,530	3,817	5,366	52,860	45.7
Flo	14,754	2,139	3,010	231	634	14,754	2,685	88	118	148	23,827	38.1
OG	11,442	194	332	11	3,066	561	11,442	904	881	2,140	19,531	41.4
Her	63,351	253	253	127	3,611	507	2,217	63,351	7,339	5,068	82,926	23.6
OP	82,360	82	82	329	4,365	1,647	4,530	8,236	82,360	14,166	115,797	28.9
OF	4,449	4	44	0	1,032	507	2,545	138	39	4,449	9,115	51.2
Total	213,830	7,851	11,588	2,421	41,630	21,486	33,581	76,266	95,111	31,341		
% f as by-catch[2]		64.0	61.3	39.0	31.1	31.3	65.9	16.9	13.4	85.8		

[1] Actual standardized fishing effort in directed fisheries.

[2] Percent fishing effort on the species when it is taken as by-catch in other fisheries.

[3] Percent of total fishing effort generated by a species fishery which has an effect on species taken as by-catch in that fishery.

Supp. Table 2. Landings standardized days fished, and C/E in SA 5 and 6, 1971.

Main species sought		Std[1] days	Species Caught									Total[3]
			Cod	Had	Red	SH	Flo	OG	Her	OP[2]	OF	
Cod	OT	1,397	2,501	865	268	324	835	865	18	-	5	5,681
	PT	1,427	7,619	1,336	-	-	-	184	-	-	-	9,139
	Total	2,824	10,120	2,201	268	324	835	1,049	18	-	5	14,820
	C/E	-	3.584	.779	.095	.115	.296	.371	.006	-	.002	-
Had	OT	4,475	5,836	4,319	599	25	1,830	2,844	-	3	-	15,456
	C/E	-	1.304	.965	.134	.006	.409	.636	-	.001	-	-
Red	OT	1,478	855	300	11,727	215	396	984	53	1	6	14,537
	C/E	-	.578	.203	7.934	.145	.268	.666	.036	.001	.004	-
SH	OT	28,697	1,716	776	802	71,321	4,684	17,187	13,862	14,043	14,461	167,549
	C/E	-	.060	.027	.028	2.485	.163	.599	.483	.489	.504	-
Flo	OT	14,754	7,688	2,906	1,987	1,569	32,527	5,835	328	445	385	68,424
	C/E	-	.521	.197	.135	.106	2.205	.395	.022	.030	.026	-
OG	OT	11,442	707	317	43	7,627	1,240	24,879	3,561	3,255	5,768	58,839
	C/E	-	.062	.028	.004	.666	.108	2.174	.311	.284	.504	-
Her	OT	57,857	868	238	1,173	8,933	1,124	4,882	201,554	26,506	13,661	258,939
	PS	5,494	-	-	-	-	-	-	47,666	1,259	-	48,925
	Total	63,351	868	238	1,173	8,933	1,124	4,882	249,220	27,765	13,661	307,864
	C/E	-	.014	.004	.018	.141	.018	.077	3.934	.438	.216	-
OP	OT	81,610	233	80	2,669	10,849	3,565	9,848	32,389	301,296	38,046	398,975
	PS	750	-	-	-	-	-	-	82	1,855	-	1,937
	Total	82,360	233	80	2,669	10,849	3,565	9,848	32,471	303,151	38,046	400,912
	C/E	-	.003	.001	.032	.132	.043	.120	.394	3.681	.462	-
OF	OT	4,449	18	44	2	2,572	1,117	5,536	546	1,465	11,975	22,731
	C/E	-	.004	.010	.001	.578	1.251	1.244	.123	.329	2.692	-

Table 2. Estimates of annual total sustainable yield for the Northwest Atlantic, 1973. From ICNAF 1973.

FEDERAL (DOI/FWS) PARTICIPATION IN THE ASSESSMENT OF GREAT LAKES FISH STOCKS

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Introduction

Among several actions affecting the Ann Arbor-based Great Lakes program of the U.S. Fish and Wildlife Service (FWS/DOI) in 1970, Executive Order No. 4 transferred all but the present biological research and sea lamprey control functions to the newly established National Marine Fisheries Service (NMFS/DOC). Implicit in these actions was the understanding, semiformally confirmed in 1974, that the FWS would sustain as an integral part of its Great Lakes research effort a Lakes-wide (fishery) resource assessment capability. The Service has faithfully done so, continuing to administer this activity out of its Great Lakes Fishery Laboratory (GLFL), fully half of whose annual budgets (about $3 million in FY 1980) have been devoted to applied research and resource surveys directly associated with the development and use of practical-stock assessment technology.

The Service's position is that only against reliable measures of the size and performance of each major component of the Great Lakes fish community can the separate or combined effects of fishing, other forms of predation, toxic substances, and habitat alteration in general be effectively adjudged. This paper briefly explains how the FWS participates in the assessment of Great Lakes fish resources whose stewardship it shares with the states and province, describes the procedures and facilities employed, and discusses research as well as information needs that remain to be fulfilled.

Resource Problems

Of the many difficulties suffered by Great Lakes fishery resources during the past century, none has drawn more attention than the decimation of the Lake trout, the Lakes' dominant, endemic predator. For many years the prime target of commercial fishermen and, in the 1950s and '60s, of the lamprey as well, the trout resource eventually fell to so low a level throughout the Lakes that a major intergovernmental effort had to be mounted to save and attempt to restore it. Through intensive control of the lamprey and stocking of hatchery-produced fish, this species is now making a successful, and what some view as a symbolic, comeback in many areas. But its restoration to complete self-sustainability--if not also to its former high levels of productivity--is being delayed by several hypothecated factors, not the least of which appears to be the premature and excessive withdrawal by sport and commercial fishermen of planted fish that survive their first four or five years in the Lakes.

Populations of other valuable native species subjected to too heavy use, to possible competitive disadvantage created by introduced or invading exotics, and/or to the effects of impaired habitat include, or have included the lake herring, especially in Lake Superior; the bloater and other chubs in Lakes Michigan and Huron; the walleye and yellow perch, particularly in Lake Erie; and the lake whitefish in several areas. Important nonindigenous species are the alewife and smelt, whose status in Lakes Michigan, Huron, and Ontario is of increasing concern owing to their role as essential forage for the lake trout as well as for burgeoning aggregations of introduced Pacific salmons.

In the case of each species, inadequately controlled use by man--among the forage species, excessive predation by other fishes--must be acknowledged as a major, if not the paramount, factor affecting fish productivity. Compounding the problem is the seemingly endless conflict among competing users (sport, licensed-commercial, and Indian-treaty fishermen) over access to those species enjoying high consumer value, namely, the lake trout, lake whitefish, bloater chub, walleye, and yellow perch. Accordingly, with the protection of these resources and the allocation of their yields inseparably confronting Great Lakes fishery managers as among today's most crucial issues, the need for statistically reliable fish-stock assessments and allowable-catch projections has become increasingly imperative.

Institutional responsibilities and arrangements

Challenged to satisfy this need are the federal and state/provincial governments, only the latter of which, however, have with few exceptions the (constitutionally vested) authority to regulate the use, and thereby ultimately to ensure the protection, of these resources. Since many Great Lakes fish stocks are transboundary, i.e., interstate, national, or international in distribution, the management of their use is understandably very complex. Federal (or national/international) oversight of such stocks, though legislatively mandated and therefore shared with state and provincial governments, is largely restricted to making available to the regulatory bodies technical advice derived from federally administered research and development efforts. A notable exception is the U.S. Federal Government's obligation to protect, through joint regulation of their use with the State of Michigan, fish stocks in waters of the upper Great Lakes ceded to certain Indian tribes by the Treaty of 1836.

Facilitating as much as any entity the interagency coordination of fishery and fishery resource management in the Great Lakes Basin is the Great Lakes Fishery Commission (GLFC), established by convention with Canada in 1956. It is mainly through the Commission's working groups (Lake and advisory committees, primarily) that federal contributions to the rehabilitation, enhancement, and protection of the Lakes' fishery resources are presented for consideration, and that cooperation with the states and province is fostered. By the same route, but not exclusively so, academic institutions provide increasingly important assistance in both scientific and technological aspects of Great Lakes resource management. In many respects, the Commission serves much the same purpose in the Great Lakes as do the regional Fishery Management Councils (provided for by the Fishery Conservation and Management Act of 1976) in the Nation's adjacent oceans.

Management Objectives

Evolving within the Great Lakes fishery research and management community is an increasingly firm consensus on long-term goals and short-term objectives. As alluded to at several points already, restoration of damaged resources, maintenance of those restored or not yet degraded, and enhancement of those for which the Lakes appear to have reserve carrying capacity are being pursued with as much vigor as diminishing money and manpower permit. There is agreement, too, that attainment of these long-range goals depends heavily on a much cleaner aquatic environment than now prevails in many parts of the Great Lakes, therefore much emphasis is understandably being placed on the "ecosystem" approach to rehabilitating the Lakes themselves, together with the living resources they harbor (IJC/Great Lakes Research and Science Advisory Boards, 1978 and 1979; Francis et al., 1979).

But as fine in principle as is the ecosystem concept, planning and implementing its innately complicated tactics will take considerable time as well as expense. Meanwhile, among other inimical and hard-to-control agents having their collective impact on the valuable fishery resources in question, fishing itself can have as profound and quick an adverse effect as any other. It therefore demands better management generally than it now receives, which, in turn, requires fundamenatlly far better intelligence about the absolute limits of the resources affected than is now available. Quite simply, the preeminent and immediate objective of the Great Lakes fishery management community today is, most will agree, the continuously up-to-date assessment of each resource being used. To permit uncontrolled use of individual fish stocks while pondering the character and mechanics of the ecosystem approach by which they would otherwise be protected is as unconscionable as ignoring the problem altogether.

Assessment strategy

As practiced by the Service's Great Lakes Fishery Laboratory, fish-stock assessment embraces all the elements technically implied by that term. Not only does it include the physical act of systematically surveying fish stocks (or populations), i.e., sampling and thereby describing them through recorded observations of their more obvious attributes, namely, size, age, and sex composition, it also entails determination of each stock's temporal as well as spatial extent, and of its relative magnitude as indexed by the rate at which individuals are captured or are otherwise monitored (e.g., sonically) during the survey process. Moreover, in accordance with our broad definition of the term, fish stock assessment involves the integration of all pertinent fishery statistics and survey data to estimate stock parameters, compute stock sixe, and, ultimately, attempt to project each stock's maximum allowable yield--i.e., the total allowable catch--as the sought-after management references mentioned previously. For greater elaboration of the points only touched on here, the reader is referred to Kutkuhn (1979).

The scope and quality of its assessment-related work is limited only by the Laboratory's survey capability and the completeness as well as the reliability of the fishery statistics at its disposal. And, though the Laboratory has been mildly criticized for its "traditional" (i.e., non-ecosystematic) approach to the assessment of Great Lakes fishery resources, it has yet to be presented for consideration with a better, immediately applicable alternative. To a very great degree, its assessment efforts along the so-called traditional lines just mentioned are dictated by the similarly traditional character of the data sets that have evolved over many years throughout the Great Lakes fishery research and management community. To change now to a better(?) assessment strategy, if indeed one could be conceived, one that would probably demand the accumulation "from scratch" of more sophisticated and costly data than are now available, would in the least be very disruptive (and possible counter-productive) at a very critical time in the management of Great Lakes fisheries.

Data requirements and systems

Ideally, the methodology employed by the Service in assessing Great Lakes fish stocks calls for complete records of the annual withdrawals of each species--by type and amount of fishing gear employed, and by month and statistical district in which fishing takes place. Related information on the size and age composition of the catches is equally essential.

At the moment, unfortunately, systems for obtaining, processing, managing, and delivering Great Lakes fishery statistics are woefully inadequate. Only in the case of commercial fisheries is performance acceptable, with all states managing in a standardized way the collection and filing of the required statistics, and the Laboratory serving by interagency agreement as the central repository for them. Glaringly deficient in comparison are the means for accommodating statistics of recreational fishing. Even though a number of (state-managed) programs for compiling this increasingly important information have been established, they vary greatly in scope and character, as well as in the quality of information they provide. Finally, in very few instances in any Great Lakes fishery are catches examined (sampled) for the valuable and necessary biological data they represent. (For a more comprehensive account of fish-stock assessment needs in the Great Lakes, refer to the recent study performed for the GLFC by Kutkuhn and Hartman [1978]).

To provide among other needs much of the biological information required by the assessment methodology described superficially above, in many instances information representing a poor substitute for that not obtained by sampling landings and checking creels, the Laboratory administers a fleet of five survey vessels, one on each of the Great Lakes. They range in length to 75 feet and in displacement to 165 tons. All are capable of gillnetting, bottom trawling, and general limnological work; three are equipped for midwater trawling as well. Their collective cost of operation now exceeds a half million dollars annually ($508K in FY 1980). All survey-derived data, like the commercial fishery statistics mentioned elsewhere herein, are computerized in standard format for ready retrieval and use.

Information synthesis

In the Great Lakes, fishing operations (U.S.) fall readily into four distinct categories, each representing in various ways the ultimate source of all assessment information employed by the Service/Laboratory and its cooperators. They are: (1) state-licensed commercial fisheries, whose principal gears are trapnets and gillnets, and whose statistics are collected and managed jointly by the states and the FWS; (2) sport fisheries, which involve exclusively the use of hook-and-line, and whose oversight is administered entirely by the states; (3) fish-stock surveys that entail mainly the use of (graded-mesh) gillnets and trawls, and [i] which are conducted cooperatively by the states and the FWS, or [ii] which are performed by licensed commercial fishermen under contract for a state (or states) and the FWS; and (4) treaty commercial (and subsistence) fisheries, whose predominant gear is the (large-mesh) gillnet, and whose statistics are compiled by the participating Indian tribes.

Because of slight variation among procedures by which the contributing parties routinely collect, classify, and record the information they provide, it is necessary to reduce all data received to a common format. The fundamental purpose is to assemble this information, from whatever source, according to standard units of space and time, such that together they and their derivatives can be expected to represent with reasonable accuracy, in each geographical area and increment of time, the density and composition of the fish stocks being assessed. For its simplicity, understandability, familiarity, adaptability, as well as utility, the statistical system described by Smith et al. (1961), into which there has since been incorporated a network of 10-min. grids, has been adopted as standard by the Great Lakes fishery management community.

Finally, the least tractable of all the parameters of the analytical model we employ is that of the rate at which the assessed stock replenishes itself, as subsequently reflected in the magnitude of recruitment into the stock's fishable component. Only very approximately are we able to measure this parameter: (1) usually in the form of an index derived annually from sample catches in small townets of the young-of-the-year (YOY) fish, which then assumes that mortality during the prerecruit phase is about the same every year; or (2), as in special cases like the lake trout, when we know the number of hatchery-reared fish planted as a necessary substitute for natural reproduction.

With the model(s) employing the parameter estimates so described, computation of standing stocks proceeds as a comparatively routine next-to-last step in the assessment process, the final one being projection of allowable catches. As a rough rule of thumb, we generally assume that the annual allowable catch of a stock considered to be in "maximum" equilibrium--that is, yearly losses do not exceed gains, while size (overall weight) remains at whatever maximum can be accommodated, along with those of other stocks, by the habitat--is somewhere between 10 and 20 percent of the stock's projected annual biomass (or total weight). Accordingly, departures from maximum equilibrium dictates corresponding reductions in allowable catches, with the residual surplus production being applied to the restoration of equilibrium. Thus the practical objective of fishery management in our view is, through limitation on catch (or on corresponding fishing effort), to ensure restoration to, then maintenance of the stock at, the highest level of productivity permitted by ecological circumstances, such that yield, like interest on the largest financial investment one is able to make, will be maximal.

Output applications

Since 1975, the Laboratory, in close cooperation with state research and management personnel, has performed assessments of at least 20 distinct fish stocks in all five Great Lakes. Most of these have been partial assessments in the sense that no more than estimation of annual stock size was the immediate objective. Targeted stocks were (and still are) mainly those of forage species--alewife, smelt, sculpin, and gizzard shad--wherever they occur in the Lakes (Great Lakes Fishery Laboratory, 1978 and 1979). Much of this work continues as developmental in nature, involving both the practical application of underwater acoustics in measuring these widely dispersed fishes (Argyle, 1979), and the use of resulting (biomass) estimates to characterize predator-prey associations in each of the Lakes.

Several have been undertaken, however, again as interagency efforts, to satisfy the pressing needs of state and provincial fishery managers for information on resource limits that could be applied quickly and easily. The best examples of those fisheries wherein stock assessments and the application of their findings have met (and continue to meet) such needs include the following:

(1) the walleye fishery of western Lake Erie, for which total allowable catches projected annually from stock assessments that began in 1973 are allocated through interagency oversight among Michigan, Ohio, and Ontario in proportion to lake surface area in each jurisdiction (Kutkuhn, 1976; Lake Erie Committee, 1980);

(2) the bloater chub fishery of Lake Michigan, in which total allowable catches (first derived in 1979) are being considered for "experimental" apportionment by interagency agreement among Wisconsin, Michigan, Illinois, and Indiana according to the relative distribution of this species throughout the Lake (Brown, 1979); and

(3) the lake trout, lake whitefish, and bloater chub fisheries in treaty-ceded waters of the upper Great Lakes, for which total allowable catches from each of the 10 or so stocks involved have been projected for intergovernmental management of these fisheries--Indian treaty, state-licensed commercial, and recreational--in 1980.

Program effectiveness

Generally speaking, these assessment initiatives, if not yet completely successful in serving intended management purposes, have nonetheless contributed significantly to the establishment of firmer and more objective bases than ever for determining the status and regulating the use of Great Lakes fishery resources. All use-allocation and innate technical problems have not been eliminated, however, and perhaps never will.

For instance, despite acceptance in principle as well as general success in application, management by catch quota of western Lake Erie's walleye fishery is still not evolving as smoothly as anticipated. Suffice it to say that overshooting of agreed-to quotas and intrajurisdictional conflict over the allocation thereof among user groups persist in at least one sector as troublesome impediments to fully effective implementation. And, in the case of total allowable catches (TACs) derived for fish stocks that are the focus of Indian fishing rights in treaty-ceded waters of the upper Great Lakes, it is still too early to tell if the application of these TACs in the context of federal regulations governing the use of the stocks in question will effectively serve their expected function: protection of the resource.

In summary, the final verdict on the practical applicability of the catch-quota approach to fishery management in the Great Lakes has yet to be rendered. The outlook for its widespread acceptance continues to be good, however, and support among fishery administrators for its further development is encouraging.

Technological deficiencies

But, as we in the business are all too painfully aware, no one (in this case, no one user group) really wants to be regulated, whether regulation entails compliance with catch quotas, restricted entry, or something else. And although a consensus in principle on the need to protect our valuable fishery resources by limiting their extraction seems to prevail, debating the reliability of the limits (TACs) imposed, the quality of the raw data from which they are derived, and/or the applicability of the theory employed, appears to be an increasingly favorite pastime--not, of course, without merit in some instances. Results of assessments performed cooperatively with others by the Service have not lacked their detractors. Ironically, they include those of us who actually do the work. Often the work is performed as a stopgap measure, with data known to be deficient, in the immediate interest of protecting the resources subject to uncontrolled use, rather than as truly scientific exercises with ample information in the more substantive interest of laying the technically unassailable groundwork for providing such protection.

To recap the shortcomings that affect most significantly our ability to provide better, more scientifically defensible assessments of Great Lakes fish stocks than are now possible, one has to focus on the following as the most serious:

(1) vastly insufficient, often discontinuous, survey data on the size composition, age structure, and reproductive performance of stocks of some species now being exploited, as well as of others with potential for development, particularly those of the whitefish and yellow perch on the one hand, and suckers and drum on the other;

(2) grossly inferior and incomplete statistics of withdrawals and corresponding fishing effort by recreational fisheries in general;

(3) almost completely lacking information on the composition (size, age, sex) of catches or landings of all species, especially those taken in sport fisheries; and, perhaps most importantly,

(4) a very imperfect understanding of the delicate balance among stocks of fish representing the same as well as different trophic levels interacting in the same habitat, and often concurrently if not differentially vulnerable to the same fishing gears, a continuing deficiency that can only be eliminated through the pursuit of more sophisticated research than has been attempted to date.

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PREDICTION OF RECRUITMENT

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Over the past two decades, scientists working in a relatively new field, "Fishery Oceanography," have tried with very limited success to find correlative physical, chemical, and biological ocean parameters which could be used to predict migration patterns, recruitment, and the large fluctuations in population biomass, so characteristic of many economically important pelagic fish species. The management of fish populations has marched apace, with decisions usually based on historical precedents, but rarely on scientific principles. Yet the collapses of recruitment-limited fish populations have had enormous economic and social effects on fishing nations, effects which might have been avoided had there been reasonable predictions on the fate of the fish populations due to fishing and the environment. Recently, it has been suggested that recruitment might yet be predicted provided a few, albeit difficult-to-measure, environmental variables were to be considered (Lasker, 1975).

In recent years, scientists in a number of fishery laboratories have found evidence that recruitment, the survival of fish from hatching to a size exploitable by a fishery, may be correlated with certain oceanic conditions. Hjort (1914) believed that the most "critical period" of a herring's life was probably during the immediate post-yolk-sac time of a day or two when the herring larva begin hunting for food; lack of food during this short time interval could only result in large mortalities and poor recruitment. Hjort offered no data to support this idea, but his concept of the "critical period" has led to a great deal of useful research on the biology of fish larvae (May, 1974).

After a 60-year hiatus, Hjort's hypothesis has been resurrected and elaborated upon, and evidence accumulated from the ocean and the laboratory to test its basic tenets. In California at the National Marine Fisheries Service, Southwest Fisheries Center (SWFC), Lasker and his coworkers have developed an extension of the Hjort hypotheses which might be called more properly a "stability" hypothesis. Briefly first-feeding anchovy (*Engraulis mordax*) larvae were found to need stable (non-turbulent) conditions in their environment to insure that food would be available in the proper concentrations (aggregated in above-threshold concentrations for feeding). Storms and upwelling events were found to disrupt larval food aggregations, and it was inferred that this disruption could result in heavy larval mortality during the anchovy spawning season. These results are available in a series of papers (Lasker, 1975, 1978, 1979, 1980; Lasker and Smith, 1977; Lasker and Zweifel, 1978; Smith and Lasker, 1978). Extending this idea, Smith and Lasker (1978) state that "a patch of anchovy larvae will have more survivors in the sea if it coincides with a succession of patches of food organisms and also if it does not coincide with a patch of effective predators." Oceanic changes maintaining or disrupting discrete patches is thus an obvious area requiring detailed study.

A regional cube-of-the-wind-speed index for the anchovy spawning grounds has been developed at the Pacific Environmental Group (SWFC) by Andrew Bakun, and has been used by Lasker (1980) to correlate with good and poor anchovy year classes. While the data are still sparse, they indicate that an index of this kind, which reflects the amount of mechanical energy which must be imparted to the sea to result in turbulent conditions, may be a valuable predictor for poor feeding conditions of larvae and hence for the degree of recruitment.

Larval fish drift and the conditions which cause it are elaborations of the Hjort hypothesis. Some scientists believe that upwelling events, if strong enough, can carry fish larvae out of good feeding areas into poor ones. At the California coast, when upwelling is weak, the stable environment inshore results in good feeding for young fish and enhanced survival. Working with fishery statistics on Pacific mackerel (Scomber japonicus) year class strength, upwelling index (Bakun, 1973) and a wind curl index (Bakun and Nelson, 1977; Parrish, 1976; and Parrish and MacCall, 1978) have shown good correlations between strong upwelling, surface transport patterns, and year class strength of Pacific mackerel off California.

Lasker (1975) has also pointed out that the biology of the larvae of the fish species being investigated must also be known thoroughly before it can be applied in predictive models. For example, using laboratory data obtained by Hunter (1972) and Hunter and Thomas (1973), Vlymen (1977) focused attention on extremely small-scale patchiness of larval fish food as a necessary condition for survival of anchovy larvae. These investions extended the Lasker and Smith (1977) patchiness concept as applied to anchovy larvae to the sub-meter scale and illustrated the necessity of research work at this scale (Owen, 1980)

On the east coast of the United States, Nelson et al. (1977) showed that menhaden larvae, which depend on estuaries for food, are carried into estuaries during downwelling periods. In this case, upwelling acts to the detriment of larval survival, but by keeping larvae offshore--a mechanism different from the disruption of food aggregations shown to be important for Northern anchovy larvae.

Active work in these areas of research undoubtedly needs to continue. The interesting findings that anchovy larvae cannot feed on filamentous diatoms (Lasker, 1975, 1978), that only certain food organisms of the right size for feeding are nutritious (Scura and Jerde, 1977), and that there is a low probability of the larva encountering copepod nauplii at first feeding (Lasker and Zweifel, 1978) provide the biological framework in which to predict the fitness of the ocean environment for survival of anchovy larvae. Similar data are needed for other pelagic fish larvae, and studies have begun on a number of commercially important species to test the "stability" hypothesis. Walsh et al. (1979) provide evidence from Peru that confirms the idea that strong winds and turbulent seas can be detrimental to the survival of the Peruvian anchovy. On the other hand, Ware et al. (1980) suggest that aggregations of food for Peruvian anchovy larvae may be a result of strong winds by means of the production of Langmuir cells and consequent accumulation of likely food items in "windrows." The space and time scales of the events being considered differ greatly, and reconciliation of these ideas requires additional research into the effects of wind-mixing and the distribution of larval fish food particles.

While the bulk of the recruitment research described here has been on clupeoid fishes, the concepts advanced may be applicable to a wide variety of fishes having planktonic larvae. Minimum concentrations of food must be present in their environment with associated stable conditions to insure that threshold-for-feeding concentrations are maintained. Cube-of-the-wind-speed, upwelling, and curl indexes are new tools which can be used by fishery scientists to correlate with larval mortality, larval food distributions, and subsequent year class strength. Biological information obtained in the laboratory now has even greater meaning since it can be used to erect useful predictive models of recruitment and, with specific data on the ocean environment, provides a hope for meaningful fishery prediction. If management wants to respond to sudden collapses or high levels of fish biomass, it must take into consideration the increasing evidence of the major effect environmental factors have on the distribution of larval fish and their food.

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CURRENT AND FUTURE STATUS OF FISHERY TECHNOLOGY IN THE UNITED STATES

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Fish technology in the classical sense is concerned with the preservation and utilization of living aquatic resources; under this definition, seaweeds and pearl oysters would be included, but, since they fall within the coastal fisheries, they are excluded from this discussion. Fishing technology has sometimes been included in the definition of fish technology, and it is certainly quite appropriate that the means of catching fish, which can have a profound effect on their subsequent preservation and utilization, should be part of the subject review. It might be reasonably asked what fish technology has to do with the FCMA and the U.S. Government agencies' regulatory responsibilities. Notwithstanding that this begs the question of the scope of U.S. federal involvement in fisheries research, concerning which more will be written later, it is appropriate to deal with this question before proceeding to a discussion of fish technology research as such.

First, it is important to emphasize that the sole purpose of fishing is to catch fish for human consumption or for animal feed. The entire catch regime must be directed towards this purpose, and it is important that the management process be operated in accord with it. Fisheries are not exercises in biological manipulation; they are enterprises for profit and product, serving the needs of both entrepeneur and consumer. Since the economic system within which we operate in the U.S.A. is geared to a free capitalist economy, management must be reasonably aligned to the needs of such a system. This idea is, of course, implicit in the concept ot Optimum Economic Yield which is embedded within the FCMA.

In our modern society fish are not retailed as raw product any more than wheat is sold as harvested grain. The product which the consumer buys is the result of a more or less sophisticated series of intermediate handling and processing steps which start at the point of capture of the fish. Indeed, the time, locus, and method of capture may all be determined as much by technology and market demand as by the availability of fish in the ocean. These factors obtain, perhaps to the greatest extent, in the case of fish caught on the high seas beyond the three mile limit. It should be noted in this regard that U.S. fisheries with few exceptions--most notably tuna--have hitherto been inshore rather than high seas fisheries. High seas fisheries require technology and handling methods for the product different from those of the traditional U.S. fisheries.

In the past, many of the fisheries coming under U.S. control as a result of the FCMA were exploited by foreign vessels using technologies which are not easily used by American fishermen, because they are intrinsically uneconomic (Russian and Eastern European) or require markets or modes of operation closed or unavailable to U.S. fishermen (e.g. Japanese). One objective of the FCMA was to facilitate and enhance development of the domestic fishing industry, and clearly to do so requires the development of techniques to enable offshore fisheries to be exploited successfully by U.S. fishermen. This objective would seem to require new technologies which the present industry probably cannot develop because of a lack of both capability and capital.

Insofar as the strengthening of domestic fisheries is felt to be in the best interests of the country as implied in the FCMA, government agencies are implicitly obligated to develop the required technology to a point at which U.S. industry can pick it up and apply it to the utilization of species harvested offshore but within the 200 mile limit. The setting of catch levels for domestic fishermen must be based to a large measure on their economic capability to capture fish. This in turn presupposes a capability to deliver the fish to domestic markets as a safe, wholesome, and reasonably priced product. Because the U.S. fishing industry is organized in small units which are geographically dispersed, it is unable to deal with the technological problems of high seas fishery without government assistance. Of course, there is ample precedent for government support in the agricultural area, and there is de facto--though financially insufficient--recognition of the need for such assistance in the establishment of the Sea Grant and Saltonstall-Kennedy Act programs.

The FCMA recognizes the stewardship of the U.S. over renewable marine resources within 200 miles of its shores. This stewardship implies a responsibility to avoid both depletion and waste of these resources. One important source of waste is the capture of fish which cannot be used and must be discarded--usually as dead animals. This situation arises in at least three circumstances: when fish are taken as a by-catch of a shrimp fishery, when mixed catches occur, and when species are caught in excess of a quota. Obviously, an improvement in the selectivity of fishing would help to reduce such waste. This improvement might require new gear developments (fishing technology) or a change in fishing strategy. In any case such developments would improve management.

Another problem of efficient management is the taking of little utilized species. In many cases, of course, such species have been quite heavily utilized, usually by foreign fishermen, prior to passage of the FCMA. Such is the case with hake and Alaska pollock. But in other cases, such as red crab, thread herring, and Atka mackerel, the species were truly little utilized. It is not clear that the new multispecies biomass management procedures will indeed confirm that such species are underutilized but if they are, this problem of fish technology is unlikely to be addressed by the industry. Nevertheless, such species under these circumstances represent a loss to the U.S. consumer.

Many of the problems associated with the new fisheries generated by the FCMA result from lack of knowledge of the properties and storage behavior of fish caught on the high seas. Obtaining such knowledge requires research of a more fundamental nature and of longer duration than that undertaken by industry. On a broader basis, there are problems within the present fisheries which, it must be recognized, affect the quality and price of fish products reaching the U.S. consumer and require technological research which is unlikely to be undertaken by industry for lack of capability and of interest. Governments since ancient times have accepted the responsibility of protecting the consumer and, in particular, ensuring the quality and safety of the food supply. The unique and extremely diverse nature of seafood products requires a special expertise which is absent in most of the U.S. agencies responsible for food control. Moreover, the long coastlines of the U.S. permit our domestic fisheries to extend from the Arctic to the tropics; hence a highly diverse series of problems, from paralytic shellfish poisoning to ciguatera and even cholera, must be dealt with. Indeed, even the universal problem of spoilage has different dimensions in the different geographical areas.

It may seem surprising, in view of the years of research which lie behind us; yet it is true that only scanty information on the detailed chemical composition of many commercially important species of fish and shellfish is available. This kind of information has become extremely important as a result of the increasing requirement for nutritional content labelling, and the situation is complicated by the fact that fish show seasonal and geographic variation in composition. It is obviously important that information of this type be obtained by scientifically reliable methods and independently of financially concerned businesses.

The food industry of the U.S. is daily becoming more technologically sophisticated. Few foods are marketed today as they were 20 years ago. New processes are applied at each stage from harvest to retail. The fish industry occupies a paradoxical position in this rapidly changing situation. On the one hand, new technologies are rapidly being applied to certain products, and on the other, traditional uneconomic and sometimes unsanitary procedures survive in many cases. Because the industry is predominantly made up of small units and involves a large number of people who are widely distributed geographically throughout the U.S.A., there seems little alternative to government involvement in the research and development activities which, in more integrated industries, are in-house responsibilities. To some extent the situation is analogous to the small farmer economy earlier in U.S. history, but it exists alongside an aggressive modern marketing system for food in general within which fish is at a disadvantage. Partly of course, this is due to the seasonal nature of fish supply, a problem which has not yet been technologically overcome.

In addition to the social importance of government research in the areas of fish preservation and processing, it is practically important for federal agencies, charged with the protection of the public, to have available current expertise in fish technology. It is difficult to conceive of effective rule-making or enforcement without a working knowledge of up-to-date practices and impending developments in utilization processes.

Economically it is patently absurd that, in the face of an increasing foreign currency deficit, the U.S., which contains within its fishery conservation zone of 200 miles the richest fisheries in the world, should import some 60% of seafoods consumed in the country. Moreover, much of the imported seafood was originally caught within the zone by foreign vessels. The situation results from the inability of our domestic industry to capture and process available fish close to our shores at a cost which will yield a final product whose price is competitive with foreign caught products. In part, this inability is indeed a problem of technology development which, it appears, requires government action to resolve.

Thus, there are a number of practical and socially and politically important reasons for a sustained U.S. government effort in technology research. They range from concern with the management role of FCMA, through the need to provide the domestic industry with assistance to utilize fish stocks within the U.S. 200 mile zone, to the concerns of the U.S. government to protect its citizens from economic exploitation and public health risks. In addition, the government has more fundamental responsibilities to propagate knowledge of our natural resources and to involve itself directly in fisheries enterprises. In regard to the first of these, concern must be maintained for the chemical and biochemical characteristics of fish and the environmental interactions, including accumulation of exotic trace substances and potential human poisons. Direct involvement, of course, includes significant hatchery activity which involves feeds and feed formulations, a proper concern of technological laboratories and, at a slightly more removed point, the utilization of fish and shellfish in military and other government feeding programs.

Above all, it should be remembered, as noted at the beginning of this discussion, that fisheries exist to provide food for man and animals and that this fundamental purpose inevitably involves technology. Since fish are a public resource whose use is managed entirely by governments (state and federal), it is essential that the government agencies should be involved in the technology of their use.

The range of topics needing attention in the fisheries technology field is very wide as befits a field which embraces the catching (harvesting) technology as well as food science and technology. Present catching methods, though highly efficient for some species and situations, are quite time-consuming and energy demanding and therefore increasingly expensive. In principle they have changed little, except in size and power, since neolithic times. We need innovative research on this entire problem, research which is unlikely to be undertaken by an industry deeply committed to boats and to traditional methods (electronically updated). Studies should be made of fixed installations, feeding stations, wind powered platforms, fish herding techniques, etc. Of course new catching technologies would have to be coupled to new methods of handling and to adaptations of processing techniques. These innovations require engineering research of a high caliber. At the least we need technological research on use of solar, wind, or wave power to reduce fuel oil requirements for existing fishing operations.

The need for technological investigation of shipboard operations is particularly urgent in view of the new offshore fisheries now being developed in the N.E. Pacific. While it is true that these are being mounted in areas and on species which have supported successful foreign fishing and processing ventures, it does not, for economic and social reasons, appear possible for the U.S. fishery to duplicate the technologies used by the foreign fleets. The development of new and applicable technologies requires information of the composition and storage properties of the species to be fished, information which is not presently available from U.S. sources. In addition, we need to study the usability of these species to produce products of the types acceptable to U.S. consumers.

Some of the species now being considered for commercial exploitation have intrinsic characteristics which make them technically difficult to handle. Indeed, these characteristics may have inhibited their use in the past. Somewhat longer term research than is normally supported by industry is needed to resolve these problems.

Procedures new to the U.S. fishing industry are being tried or are under consideration. These include freezing at sea for secondary processing ashore, storage of chilled fish in controlled atmosphere containers--either in bulk or individually--and minced (deboned) fish production. Though quick freezing was originally developed for fish products by Clarence Birdseye over 50 years ago there is still much to be learned about the chemistry and storage stability of fish during freezing and during storage in the frozen state, particularly in the case of species which are relative newcomers to U.S. catch statistics. Controlled atmosphere storage, in which oxygen is reduced and carbon dioxide increased, is a fairly old technique which has been revived and applied to fish on a commercial scale for the first time in recent years. It is a method which holds high promise to improve the quality of fish reaching consumers and may make possible more attractive and convenient retail units through centralized prepackaging. However, it is a method with potential public health risks because of the hazard of the growth of dangerous bacteria, and research is needed to reduce this risk to a neglible level and to enhance the effectiveness of the procedure.

Minced or deboned fish has long been used by the Japanese for production of Kamaboko and other forms of fish pastes, fish sausages, and hams. In recent years this process has been widely touted as a method for preparing small fish, edible fillet wastes, and fish giving low flesh yields by traditional processing methods. There is some production of minced fish which is used in preparing fish portions, fish sticks, fish patties, and various battered-breaded products. However, the extent of the development has been limited by fundamental problems of technology due to the disruption of muscle tissue by mincing, which causes release and mixing of enzymes and substrates, and permits wide inoculation with spoilage bacteria. This promising process merits more extended research to facilitate its application to underutilized species and to help ensure safe and good quality products for the consumer.

Safety and good quality are fundamental objectives of technological research applied to food products and furnish a convincing rationale for continuing and expanding research in the more fundamental food science aspects of fish technology. These aspects include nutritional chemistry, microbiology, toxicology, and studies of functionality. The sponsorship of such studies, because of their long term nature and the general importance to both consumer and producer of the topics studied is appropriately the responsibility of government agencies. Again the role of government as a regulator of food and food safety requires that such information be developed and made available to concerned parties.

Research should be conducted on the suitability of abundant but little used species for human or animal food. When successful this research can lead to the development of new fisheries which relieve pressure on older heavily exploited stocks. Such speculative research can only be financed initially by public moneys.

There should be continued research into risks, associated with consumption of marine products, which relate to environmental factors or processing activities. Examples of such risks are heavy metals contamination, pesticide residues, petroleum products, natural toxins such as ciguatoxin and saxitoxin, and process changes such as dimethylamine production in frozen fish and nitrosamines in smoked fish. Such research should be directed to both detection and avoidance of the hazard: avoidance might involve an improved technology of processing. Again, these are areas of broad public concern which should certainly be in the province of government.

Technological research is a necessary component of the broad fields of aquaculture and mariculture, including feed and feed component research, as well as studies of the best methods for handling and processing the end product. Flavor, appearance, and texture are important qualities of fish to the consumer, and the influence of feed components on these properties can be considerable. Food safety considerations require that ingredient control and handling practices avoid the contamination of fish with dangerous substances or microorganisms. Recent European studies have suggested an increased botulism in some cultured fish.

Many of the research topics referred to above are being studied in U.S. government laboratories or by recipients of federal grant or contract support. Unfortunately, much of the research is ad hoc in nature, and projects are of too short duration to do more than unveil the problem in many cases. There is an insufficient effort at the more basic levels of research into the chemical, biochemical, and biological mechanisms in fish and shellfish after harvest and during processing and storage. This situation is particularly unfortunate, since it is this type of research which provides the insights and understanding which lead to new technologies.

There are three principal mechanisms whereby the federal government supports technological research. Such research is performed directly by designated groups in the Regional Fishery Centers: Northwest and Alaska, Northeast, and Southeastern. Each of these technology laboratories engages in studies which are relevant to the regional fisheries and in some work of a more national concern. A second support mechanism is Sea Grant. Under this program, research in various aspects of fish technology is being carried out at universities and colleges. The third route of support is Saltonstall-Kennedy funds. These moneys, derived from duties on imported seafood products, are used in part to fund developmental projects which usually involve a strong technological component. Some S-K money goes directly to regional National Marine Fisheries Services laboratories for applied projects.

Subjects under study in NMFS laboratories include microconstituent research, involving mainly heavy metals, pesticides and lately mutagens, safety aspects of controlled atmosphere storage of fish, improved holding techniques and processing, species identification and composition, storage quality, deteriorative processes, toxicology, and microbiological studies including viruses and botulism. Each laboratory is also conducting projects on utilization of underutilized species. The total budget of the laboratories appears to be about $4.2 million, including S-K money and other special funds. The laboratories seem to be well equipped for research, at least at the bench levels. It is unclear whether adequate shipboard facilities are available, however. Most of the reported work seems to be done on small vessels, most of which are chartered. In view of the anticipated increase in U.S. high seas fishery and shipboard processing, it would seem advisable that shipborne technological research capability should be made available.

Work at the universities is highly diversified and includes studies of safety, quality, underdeveloped species utilization, toxicology, aquaculture feeds, newer preservation methods, composition, microbiology, and biochemistry of fresh and preserved fish and novel processing procedures. Unfortunately, the nature of Sea Grant program reviews tends to promote ad hoc rather than more fundamental, and long-term, studies which can most appropriately be followed in a university environment. Consideration should be given in the future to longer term funding of fish technology research at the universities with the objective of encouraging more fundamental research in the properties of fish and shellfish as related to their use for human food.

However, the advantages to be gained by maintaining the diversity of projects seen under the present system should not be ignored. A fine balance should be struck between the long term and short term projects.

The revised S-K program, in which much of the money is channeled through regional "Foundations" which are mainly "non-profit" associations involving industry, is too recent to be evaluated. There are obvious dangers in the arrangement which involves a good deal of what one hopes is enlightened self-interest on the part of the participants. However, this arrangement could result on expeditious testing of technological research in practical situations and the accelerated reduction of theory to practice. At present it would seem advisable that there be some form of professional technological involvement in the funded projects so that money is not wasted needlessly.

Consideration of the needs and current activities in fish technology inevitably leads to the question of the future patterns for such activities. In some respects, this question is unanswerable because development in the basic sciences may affect technology in unforeseeable ways. Directions of research in basic sciences suggest that there will emerge better understanding of the fine structure and functional biochemistry of marine animal tissues which could result in an improved technology of controlling and testing for quality in seafood products. This understanding is important since it relates directly to waste, consumer demand, pricing, and regulatory control. This is a research area which merits continued attention.

Food safety and the occurrence of hazardous constituents are perennial matters of public concern which are receiving increasing attention and are likely to remain important research areas for the future. Obvious targets for research include viruses, fish toxins, carcinogens (mutagens), and environmental toxicants.

Nutritional attributes of fish and shellfish and the effects of processing on them are likely to remain topics of high public interest which will need further research. Truth in labelling legislation has created a need for additional information on seafood components which was not thought to be important in earlier studies.

The scarcity and expense of fuels inevitably raises questions of energy use in the future. Undoubtedly research on energy efficient systems for harvesting and processing fish will be important in coming years. Such research might involve the application of renewable energy sources such as sunlight or sea motion or the development of novel processing technologies requiring less energy than traditional methods.

The present pattern of consumer demand suggests that there will be continued and indeed accelerated development of table or oven-ready seafood products in the future. This will involve using techniques which are not yet fully developed at present and which carry potential dangers. Consequently, additional research into these methodologies should be conducted. Examples of such systems include controlled atmosphere packaging and flexible pouch fully processed products.

The conversion of fish and fish waste unusable for human food to fish meal and oil is likely to continue as an important process in the next few years. Technological research in this area is keyed to nutritional quality and safety, though it is linked to concern for waste utilization and pollution abatement. It is possible that the waste utilization research could result in entirely novel methods of retrieving presently wasted resources which occur at sea (e.g., shrimp by-catch) and onshore. This type of research could be extremely important for the development of latent resources which require complete utilization of the catch to make their harvest an economically viable prospect. There should be some attention given to the removal of barriers to the use of fish oils for human food within the United States.

Aquaculture and mariculture seem to be on the brink of major expansion as commercially practical food production systems. This will require the varied technological research already indicated earlier in this paper.

In addition to these areas of future importance and to others which are not yet obvious, there will always remain the "bread and butter" studies which are necessary to support the government's role as the protector of the consumer. The intensity of such studies in the future is difficult to project because they depend in part on unforeseeable events, but assuredly they will continue.

All of the work outlined above will require a continuing supply of well qualified researchers provided with adequate facilities, and it is in this area that the greatest questions lie. The level of support for fish technology training within the universities has not kept pace with the needs created by a burgeoning industry. Universities experience a particular problem with equipment. Most institutions are forced to train students on outdated and obsolescent equipment because the cost of new items is too great for their limited budgets to cover. This is in fact a general problem in the applied fields where specialized industrial-type equipment is used. In the case of fisheries, such equipment includes items such as research fishing vessels which are difficult to justify in university budgets and processing equipment for technology work. Because of the importance of university programs in supplying researchers and other trained professionals as well as their actual involvement in applied fishery research, it is very necessary that provision of aid to acquire modern equipment including fishery research vessels should be included in future U.S. government planning for research support.

SALMON RANCHING

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Introduction

Salmon ranching has become an important economic activity in the North Pacific Ocean where it continues to grow at a rapid rate. Salmon are also ranched on a modest scale in the North Atlantic Ocean and the Great Lakes and, on a small scale or experimental basis, in the South Pacific Ocean, Caspian Sea, and elsewhere.

Release of artificially propagated juveniles of the genus *Oncorhynchus* (Pacific salmon) and the genus *Salmo* (Atlantic salmon and trout) into natural waters is included in my definition of salmon ranching. Juveniles are released by public and private ranching institutions to support recreational and commercial fisheries and for proprietary harvest.

Salmon are anadromous species which afford significant advantages for ranching:

1. Strong homing behavior during spawning migrations provides a self-herding mechanism.
2. Some species undertake transoceanic feeding migrations and utilize food sources in pelagic waters.
3. Zooplankton and forage fish, which are typically scattered within a large volume of water, are converted into a form of protein which can be easily harvested and processed for human consumption without large expenditures of energy.
4. Technology for artificial propagation is well advanced and steadily improving.

Principal Species

Principal salmonid species involved in salmon ranching include the following:

1. Chum salmon (*Oncorhynchus keta*) are ranched most extensively in Japan and eastern USSR. Programs are under development in Alaska, British Columbia, the Pacific Northwest states, and Republic of Korea. Chum are being introduced to the South Pacific Ocean (Chile) and the Caspian Sea (USSR).

2. Pink salmon (Oncorhynchus gorbuscha) are ranched most extensively in eastern USSR, Alaska, and British Columbia. Programs are under development in Japan and Pacific Northwest states. Pinks have been introduced to the North Atlantic Ocean (USSR) and the Great Lakes (Canada). They are being introduced to the Baltic Sea (USSR).

3. Chinook salmon (Oncorhynchus tshawytscha) are ranched most extensively in the Pacific Northwest states and California. Programs are under development in British Columbia and Alaska. Chinook have become established in the Great Lakes (USA) and the South Pacific Ocean (New Zealand) and are being introduced to Chile and the Mediterranean Sea (France).

4. Coho Salmon (Oncorhynchus kisutch) are ranched most extensively in the Pacific Northwest states. Programs are under development in British Columbia and Alaska. Coho have become established in the Great Lakes (USA) and are being introduced to the South Pacific Ocean (Chile) and the Sea of Japan (Republic of Korea).

5. Sockeye salmon (Oncorhynchus nerka) are ranched most extensively in Alaska and British Columbia. There are minor ranching projects in the Pacific Northwest states.

6. Cherry salmon (Oncorhynchus masu) are ranched in Japan. USSR is developing a ranching program.

7. Atlantic salmon (Salmo salar) are ranched in most countries bordering the North Atlantic Ocean and Baltic Sea. Most extensive programs are in Sweden, Finland, and USSR.

8. Steelhead trout (Salmo gairdnerii) are ranched in the North Pacific Ocean by the Pacific Northwest states and British Columbia, and have been introduced to the Black Sea (USSR).

9. Caspian salmon (Salmo trutta) are ranched in the Caspian Sea by USSR and Iran.

Production

Notwithstanding declining abundance, natural stocks remain dominant contributors to the world supply of salmon. Salmon ranching is, nevertheless, undergoing rapid expansion to utilize more fully the capacity of marine waters to grow food and to satisfy the growing demand for salmon. Some examples are described here.

Japan sustains an intensive near-shore coastal fishery for chum salmon with hatchery fish. About half of the world supply of chum salmon is caught by Japanese fishermen, and about half of the Japanese catch is from the near-shore coastal fishery, which depends on hatchery production. It is conceivable, therefore, that one-fourth of the world supply of chum salmon originates from Japanese hatcheries. Large quantities of chum salmon are also produced by Soviet hatcheries.

Pacific Northwest fisheries for coho and Chinook salmon are supported to a large extent by ranched fish. Releases of ranched fish from North America in 1977 included about 88 million juvenile coho and 217 million chinook. More than 95 percent of them came from hatcheries in the Pacific Northwest and California. These releases are of sufficient magnitude to account for the majority of coho and chinook harvested by commercial fishermen in the Pacific Northwest.

Approximate numbers of artificially propagated juvenile salmon released into the North Pacific are as follows:

2.0 billion chum
0.5 billion pink
0.2 billion chinook
0.1 billion coho
0.1 billion sockeye

2.9 billion Total

Based on observed survival rates, these ranched fish are estimated to contribute between 15 and 20 percent of the poundage of salmon harvested from the North Pacific. Production of ranched fish has increased four-fold in the last two decades, and there is every indication of continued rapid growth over the foreseeable future.

Salmon ranching in the North Atlantic is conducted on a relatively modest scale when compared to the North Pacific (tens of millions vs. billions of juveniles). Principal species ranched are Atlantic salmon and pink salmon.

Pinks were first introduced in 1956 from Sakhalin Island to the White and Barents Seas. Returning adults number into the hundreds of thousands in odd years, and they have colonized streams in Norway as well as western USSR (Markevich, et al., 1978; Smirnov, 1978).

Chinook and coho salmon have become acclimated to the Great Lakes from introductions in the 1960's, and ranched fish support important recreational fisheries.

USSR has been ranching chum salmon in the Caspian Sea since the 1960's. There are reports of returning runs in the Caspian, but eventual success of the program remains to be evaluated (McNeil, 1979).

Experiments are underway in France to introduce chinook salmon to the Mediterranean Sea (Dr. Frideric Mazeaud, Institut Oceanographique, personal communication).

Salmon ranching in the southern hemisphere is concentrated mainly in the South Pacific Ocean, but there is interest in ranching the South Atlantic Ocean from hatcheries located in the Falkland Islands (Dr. John Thorpe, Department of Fisheries for Scotland, personal communication). Chile is one of two countries where salmon ranching is practiced in the South Pacific. Only experimental releases of chum, chinook, and coho salmon have been made in Chile. Returning adults of chinook and coho have been spawned (Mr. Richard Noble, DOMSEA Farms, Inc., personal communication). New Zealand is the the other South Pacific country where salmon ranching is being evaluated. Natural runs of chinook salmon have become established from earlier transplants, and small-scale ranching projects are limited to these stocks.

Technology

Artificial propagation of salmon embodies a broad spectrum of control over reproduction and rearing. Production systems range in complexity from relatively simple operations for stocking natural stream beds with artificially fertilized eggs to complex facilities for growing juveniles in controlled, artificial environments until they migrate to sea. Site selection is discussed in this section along with status of technology on adult handling, egg collection and handling, egg and alevin incubation, juvenile rearing, and juvenile release.

Site Selection

Biological and physical criteria are equally important in selecting sites for salmon ranching projects. Selection of target species and stock(s), disease transfer, conservation of natural populations, and carrying capacity of nursery waters receiving artificially propagated fish need to be considered.

Use of native fish for brood stock is likely to reduce uncertainties on survival and homing (McNeil, 1979; Bams, 1976). Nevertheless, transplantation of stocks is often a necessity, even with increased uncertainty about disease transfer and incompatability of a stock to a new environment.

Disease transfer is an especially serious issue. In Alaska, the wide-spread distribution of infectious hematopoietic necrosis (IHN) virus disease in natural stocks of sockeye salmon has been recognized (Grischkowsky and Amend, 1976), and has caused the state of Alaska to re-examine salmon ranching projects.

Proper management of fisheries on mixed naturally and artificially propagated populations will produce surplus fish returning to ranching facilities. Both social and biological problems are associated with these surpluses, and management agencies are often criticized by commercial fishermen when surplus fish return. Fishermen commonly demand more liberal fishing privileges without full appreciation of attendant risk of overfishing natural stocks.

There is a general understanding of limitations on carrying capacity of freshwater nursery waters. The question becomes more complex in marine nursery waters where information is less complete. It seems timely for major salmon producing countries to share information and initiate cooperative studies on carrying capacity of marine waters. The allocation of grazing rights for artificially propagated salmon is likely to become a critical issue.

Fresh water of suitable quality for salmon ranching is becoming a scarce commodity in many areas, and complex environmental control systems are being engineered to recondition water for raising salmon. Site selection criteria for hatcheries with sophisticated environmental controls could increasingly include factors such as availability of waste heat from thermal power plants or industrial complexes, the logistics of transporting smolted juveniles to satellite release/recapture sites, and the availability of waste protein from fish processing facilities for conversion into fish food.

Adult Handling

Because artificial propagation potentially could generate a much higher return per spawner than natural propagation, successful salmon ranching can generate substantial surpluses of adult salmon where the fishery is regulated to conserve natural stocks. Policy on utilization of surplus salmon from ranching projects varies considerably among governmental jurisdictions, but economic value of these surplus fish is increased by harvesting them as far in advance of maturation as feasible. Recapture of surplus fish in salt water generally provides a product with higher market value than recapture in fresh water, and new technologies utilizing salt water release/recapture facilities are being evaluated.

Salmon held in captivity for maturation sometimes experience unacceptably high pre-spawning mortality. Further research is required to develop methods to minimize pre-spawning mortality of brood fish and to insure high egg fertility through more effective control of environment, disease, and other factors which may impose stress. Delay or acceleration of maturation through control of environment or injection of steroids or hormones could become important tools for salmon ranching.

Addition of organic attractants to water at release/recapture facilities to control homing response shows promise for application in salmon ranching (Cooper and Scholz, 1976). The evidence supports the hypothesis that olfactory cues are responsible for recognition of "home" water (Madison, et al., 1973); but many questions remain to be clarified: duration of exposure, conditions of exposure, physiological state of juvenile fish at time of exposure, and organic constitutents which provide cues for homing. There are also unresolved questions about the effect of pheromones on reinforcement of homing behavior (Fontaine, 1976).

Egg Collection and Handling

Expansion of salmon ranching programs is contributing pressure for transfer of eggs among watersheds with associated risk of spreading disease agents. Development of cost-effective systems to quarantine eggs for disease certification is recognized as a needed measure to minimize the spread of disease agents.

An egg quarantine system requires a source of disease-free water and a capability to sterilize effluent water before it enters natural surface waters. Pretreatment of water with ultraviolet light, chlorine, ozone, or other germicidal agents would likely be required unless disease-free ground water should be available. Post-treatment of effluent water from a quarantine facility with a germicidal agent might be avoided where infiltration into the ground is a possibility.

Transportation of unfertilized eggs has facilitated the transplantation of salmon (Poon and Johnson, 1970). More work is needed to develop techniques to extend the period of viability of salmon sperm. Cryopreservation of sperm (Horton and Ott, 1976) holds promising applications.

Organic iodine compounds have proven helpful in treating eggs against pathogenic agents which adhere to the egg surface (Amend, 1974). Other prophylactic chemicals commonly applied to eggs are no longer approved by U.S. food and environmental regulatory agencies (Meyer, et al., 1976).

Egg and Alevin Incubation

Depending on suitability of water and other environmental factors, inexpensive salmon ranching projects can be designed around artificial stocking of natural or artificial stream beds (incubation channels) with eggs. Hydraulic methods for injecting newly fertilized "green" eggs or eyed eggs into incubation channels are being developed and evaluated (Jones, et al., 1977). Stocking densities as high as 14,000 eggs per M^2 of stream bed have been tested successfully in an artificial incubation channel (Thomas, 1975). A relatively constant flow of good quality water can sometimes be supplied to natural or artificial incubation channels from spring-fed or lake outlet streams without installing costly flow-control structures.

Artificial spawning channels are similar to egg incubation channels with regard to design criteria. Adult salmon are allowed to spawn naturally in the spawning channel. Eggs are seeded artificially in the incubation channel. Resultant egg densities can be much higher (perhaps five-fold or more) in the incubation channel than in the spawning channel because of added space requirements for natural spawning.

A recent workshop on substrate incubators (Bams and Simpson, 1977) has identified six requirements in incubation:

1) a clean, continuous water supply;
2) adequate oxygen availability;
3) appropriate temperature regimes;
4) continual darkness;
5) rugose substrate; and
6) a medium to separate alevins into small clusters.

Substrate incubation techniques attempt to satisfy all criteria listed above. Japan and the USSR were first to apply substrate incubation on a large scale. Most hatcheries in North America retain incubation systems using smooth substrates; but recent innovations suggest a developing trend toward substrate incubation, especially in Canada and Alaska.

A number of design configurations have been described for substrate incubators (Bams and Simpson, 1977) and more are under development. Some systems impose a substantial requirement for handling bulky materials such as gravel and artificial filter bed materials.

Washington State hatcheries have adopted egg trays which are suspended in raceways (Senn, et al., 1973). These in-pond incubators allow multiple use of raceways for incubation of eggs and alevins and for feeding juvenile fish. A private hatchery (Oregon Aqua-Foods, Inc.) has combined features of substrate and in-pond incubators into a system for handling large numbers of eggs while attempting to satisfy the six criteria listed above.

Juvenile Rearing

Advances in knowledge about physiological, behavioral, nutritional, and environmental requirements of salmon have provided a basis to raise salmon in controlled environments. "Controlled environments" are defined here to include a broad range of applications of technology ranging from intensively managed natural ecosystems stocked with naturally and/or artificially propagated juveniles to completely artificial systems where water quality and other parameters are rigidly controlled. The type of system employed for a particular salmon enhancement project should be designed to optimize growth, health, and survival with cost-effective technology tailored to take full advantage of natural or man-made resources at the site.

An example of a ranching project using natural ecosystems is a lake with a waterfall on the outlet to prevent return of adult salmon. Lakes of this type have been stocked with salmon fry and fingerlings with resultant good survival to smolt and adult stages (Heard, 1978). Ranching based on stocking natural lakes requires an incubation system along with knowledge about the capacity of natural lake waters to grow juvenile salmon to smolt size. Recent studies on artificial fertilization of salmon nursery lakes (LeBrasseur, et al., 1978) open the possibility of increasing the number of salmon smolts produced through controlled additions of inorganic nutrients.

Examples of intensive control of environmental factors include hatcheries with water re-use systems (Meade, 1974, Liao and Mayo, 1974). Up to 90 per cent of the water is reconditioned to remove waste metabolites and disease agents and to control temperature and dissolved gas content for recirculation through a "re-use" hatchery system.

Modern "single pass" hatchery systems sometimes employ sophisticated methods to control water quality. Increasing use is being made of waste heat from thermal power plants and industrial processes to regulate water temperature in hatcheries. Water is being disinfected with various germicidal agents, including ultraviolet light, chlorine, and ozone. Capabilities are also being designed into new hatchery systems for quarantine of eggs for disease certification, substrate incubation of eggs and alevins, production of multiple crops of salmon smolts on an annual basis, and transfer of smolted juveniles to salt water for acclimation and imprinting to coastal sites prior to release into the ocean. Some salt water facilities are designed for recapture of returning adults and maturation of brood stock.

Even though nutritional requirements of salmon are imperfectly understood (National Academy of Sciences, 1973a; Halver, 1972), diets are undergoing steady improvement. The cost of raising some species (e.g. coho, chinook, and Atlantic salmon) is in large part due to the cost of feeding fish. Efforts to reduce feeding costs can best be directed at increased utilization of waste fish processing plants and at formulation of diets which reduce transportation, storage, and labor costs. There is also a growing need to identify substitute proteins for fish meal and oil. Cost reductions in feeding fish are advantageous provided they do not impact unfavorably on marine survival, because a small change in survival can exert a major impact on profitability of salmon ranching.

Known control measures are reasonably good for most fresh water diseases, with the possible exception of viral diseases, and are poor to fair for salt water diseases (National Academy of Sciences, 1973b). Unfortunately, U.S. government restrictions against use of certain prophylactic chemicals (Meyer et al., 1976) have negated much previous progress in disease control. The need to obtain governmental certification for use of chemicals in aquaculture has become urgent in the U.S. There is also a recognized need for development and government certification of bacterins and vaccines.

Size and configuration of ponds, tanks, and raceways for growing juvenile salmon can be dictated by operational, biological, and engineering criteria; site development problems; species mix and production schedules; construction and operation costs; and pollution control requirements. Relationships between flow rate, water volume, and stocking density are usually dictated by fish size and water temperature (Liao, 1971; Westers and Pratt, 1977). However, more information is required on the relative importance of density and flow rate.

Juvenile Release

Juvenile salmon are typically released as smolts from ranching facilities after they have become physiologically adapted for life at sea. Exceptions are when pre-smolt juveniles are stocked in fresh or brackish water nursery areas for additional growth on natural foods before they migrate to sea.

Size and age at time of smolt transformation varies somewhat among species and populations of salmon and can be controlled to some extent by manipulation of environmental factors. Photoperiod is known to have an influence on smoltification along with fish size and water temperature (Hoar, 1976). The use of artificial photoperiod and controlled water temperature holds promise of extending the period when juvenile salmon can be introduced to salt water by accelerating or delaying smolt transformation.

When introduced to salt water, salmon smolts require about 36 hours for ionic balance in body fluids to stabilize (Miles and Smith, 1968; Houston, 1959). Thus, introduction to salt water stresses fish, and methods to monitor smolt transformation would be very useful to salmon ranching programs. The amount of gill adenosine triphosphatase activity is one indicator of smolt development (Zaugg and McLain, 1974), but other indicators such as blood salts might also prove to be useful.

Some salmon ranching projects are beginning to make use of salt water release facilities for acclimatization of juveniles to sea water. Salt water release facilities, when linked with fresh water hatchery facilities, comprise an integrated salmon ranching system. It is possible for the fresh water hatchery to be sited inland where fresh water and other resources required by the hatchery might be more easily obtained than at a coastal release site. Such a system requires juveniles to be transported between facilities by land, water, or air. The technology for transporting salmon is functional, but procedures for minimizing stress are imperfect.

Institutional Arrangements

Laws and administrative regulations which establish public policy for salmon ranching vary greatly among governmental jurisdictions. Some governments have adopted legal frameworks to allow private ownership of salmon, while others allow only public ownership. Private ownership is typically restricted to the period that fish are within waters prescribed for exclusive use of licensed private ocean ranching facilities. Thus, fish released from private facilities remain a public resource for much of their life while grazing in public waters. They are managed by public agencies and are subject to laws, regulations, and treaties governing harvest by recreational and commercial fisheries.

Most salmon hatcheries in the United States are operated by state and federal agencies and are supported by public tax revenues. Interest in private hatcheries is manifested, however, by operation of private profit hatcheries in California and Oregon, private nonprofit hatcheries in Alaska, and Indian hatcheries in Washington and Alaska.

Private hatcheries can range from tax-paying, profit-oriented enterprises to tax-exempt, nonprofit corporations. Private hatcheries generate the same benefits to fishermen, processors, and other traditional user groups as public hatcheries.

Ocean ranching laws and regulations are primarily the responsibility of state governments in the United States. The federal government has jurisdiction where Indian treaty rights are involved and in marine waters which lie beyond the territorial sea. The federal government also regulates importation of live fish and other biological specimens into the U.S.A., use of chemicals for fish husbandry, and discharge of waste water from aquaculture facilities. However, most laws and regulations which apply to artificial propagation of salmon orginate in state legislative bodies and regulatory agencies.

Alaska

The Alaska legislature has taken several precedent-setting actions since 1974 (Robinson, 1977) which have authorized the following:

1) private ownership of salmon by qualified private non-profit hatchery corporations;

2) regional associations of commercial fishermen, processors, sportsmen, personal use fishermen, and other user groups to assist the state with rehabilitation of depressed salmon fisheries;

3) state grants to qualified regional associations for planning;

4) state fisheries enhancement loan program to provide low interest loans to qualified nonprofit private hatchery corporations for construction and operation of hatcheries; and

5) tax exempt salmon enhancement authorities as political subdivisions of the State of Alaska.

None of these initiatives would have been possible before passage of a referendum amending the Alaska constitution in 1972 to allow limited entry to fisheries and aquaculture. Prior to 1972, the constitution effectively barred private ownership of salmon in Alaska, and initiatives in salmon ranching were limited to programs undertaken by government.

Washington

The Washington legislature passed a law in 1971 which authorized private fish farming. Private operators were initially allowed to release salmon with written approval of the Director of the Washington Department of Fisheries. However, this policy has been rescinded, and salmon must now be retained in captivity by private operators. Legislation to broaden the 1971 law to allow salmon ranching by private firms has consistently failed to pass in the Washington legislature. Salmon ranching in Washington is, therefore, a governmental activity with the exception of Indian tribes which have treaty rights with the United States government.

Indian treaty rights allow tribes to grow juvenile salmon in reservation waters and release them to emigrate to sea. Sixteen Indian tribes are actively engaged in salmon ranching Washington State with financial and technical support from the federal government. More than 28 million juvenile salmon and steelhead were released from tribal hatcheries in 1979.

Oregon

Oregon has adopted the most liberal policy of any state to encourage private investments in salmon ranching. Oregon law allows hatcheries to operate for profit.

Legislation for private hatcheries was first passed in 1971. The law initially was limited to chum salmon, but was broadened in 1973 to include chinook and coho salmon, and in 1979 to include pink salmon. Oregon law specifies that privately operated release/recapture facilities be located near the ocean. Salmon released from private facilities are a public resource while in public waters. Private hatcheries are required to purchase commercial fishing licenses to harvest returning fish, and must pay poundage taxes to the State of Oregon for all recaptured fish. Through 1979, 20 permits had been issued to private firms to release 180 million juvenile salmon.

California

A law was passed in 1968 to allow one private firm to release salmon for ocean ranching at a specified location. Efforts to pattern ocean ranching legislation after legislation in Oregon have failed.

Outlook for North Pacific

Should growth of salmon ranching in the North Pacific Ocean continue at the rate experienced in the last two decades, approximately six billion juveniles will be released by 1990. Events suggest that continued rapid growth should be anticipated:

1) Japan is embarked on a five-year plan to increase hatchery production of chum salmon by 50 percent and is evaluating possibilities to ranch coho salmon.

2) Soviet authorities have expressed an interest in continued rapid expansion of pink and chum salmon ranching and are evaluating ranching of cherry and coho salmon.

3) Alaska has authorized $100 million in bond issues for new public ranching facilities and has provided state low interest loans and grants for nonprofit private hatcheries.

4) Canada has authorized $165 million (Canadian) for new public ranching facilities in British Columbia.

5) Washington has authorized $33 million for new public ranching facilities. Legislation has been proposed for federal investments in ranching facilities to provide more fish for Indian fisheries.

6) Oregon has issued 20 permits to private firms to release 180 million salmon smolts.

7) California is reviewing proposals to expand public ranching programs.

Federal Facilities and Programs

NOAA supports considerable research on salmon ranching through Sea Grant, National Marine Fisheries Service laboratories, and contracts to state agencies. Other federal research on salmon ranching is supported by the Fish and Wildlife Service through their own laboratories, cooperative fishery units, and contracts to state agencies.

Principal Sea Grant universities engaged in salmon ranching are Oregon State University, University of Washington, and University of Alaska. In addition to laboratories on main campuses, universities operate laboratories and experimental hatcheries on the Oregon coast at Yaquina and Netarts Bays, in Puget Sound at Big Beef Creek, and in Alaska at Auke Bay and Seward. The University of Alaska Sea Grant Program has provided support to a salmon ranching project at Sheldon Jackson College, Sitka.

NMFS laboratories and field stations engaged in research on salmon ranching are located at Yaquina Bay, Oregon; Seattle and Manchester, Washington; and Auke Bay and Little Port Walter, Alaska.

FWS is engaged in salmon ranching research at laboratories and field stations in California (Coleman National Fish Hatchery), Washington (Seattle and Abernathy Creek), and Alaska (Anchorage). Cooperative fishery units at Humboldt State University, Oregon State University, and University of Washington also do research on salmon ranching.

Coordination

Numerous federal, state, university, and private organizations are involved in salmon ranching research. Office of Sea Grant Programs plays the major role in coordinating university programs. Coordination of programs at federal laboratories is an internal agency activity for the most part. State agency programs are typically supported by a combination of state and federal funding sources.

Stock assessment through coded wire tagging studies is one area where coastwide coordination is being implemented through a single agency. Salmon smolts are being tagged by state and federal agencies, Canadian agencies, and private ranchers to evaluate marine survival, ocean distribution, and fishing rates on ranched salmon stocks. Assignment of tag codes and reporting of recaptured fish is being coordinated through the Pacific Marine Fisheries Commission with financial support from the member states (California, Oregon, Idaho, Washington, and Alaska) and NMFS. Canada shares expenses through exchange of services. There have been three-year delays in reporting results of stock assessment studies due to inadequate, long-term funding. Approximately $2 million is required annually to implement a program where results are reported within six months after the end of a calendar year.

Limitations to the capacity of marine waters to grow salmon are not well understood. There is a possibility, nevertheless, that countries will someday compete for "grazing rights."

Estuarine and marine ecosystem studies are fragmented among the several university, federal, and state agency laboratories sharing an interest in questions related to ecological impacts of ranched salmon and capacity of marine waters to grow salmon. Because of the high cost of ocean research, a coordinated plan is needed to seek answers to timely questions related to the proper role of salmon in the marine ecosystem and to public policy on stocking levels.

There are a number of service activities which would benefit greatly from coordination. Foremost is the development and provision of salmon brood stocks. Other essential services include disease diagnosis and certification. University, federal, and state laboratories could potentially participate. It may be useful to explore opportunities to apply concepts of agricultural experiment stations to salmon ranching.

National policy remains vague on aquaculture. Attempts to establish a National Aquaculture Organic Act have been unsuccessful. Responsibility for aquaculture research is shared by the Departments of Commerce (NOAA), Interior (FWS), and Agriculture. An interagency coordinating committee has provided some leadership at the national level, but responsibility and accountability of individual agencies are not clearly defined.

Role of the federal government in research lies largely in two areas:

1) improvement of technology and

2) management of mixed stock fisheries.

The federal government provides funds for massive hatchery mitigation programs in major western river basins such as the Columbia and Sacramento. Federal funds also support salmon ranching projects by seventeen treaty Indian tribes in Washington and Alaska. These major investments require substantial commitments of federal funds to research on hatchery technology. NMFS and FWS administer much of the funding through contracts, grants, and in-house research projects. There are also a number of Sea Grant-supported research projects on salmon ranching technology.

It is difficult to evaluate how effectively federal research funds on salmon ranching technology are being utilized by the various federal and state agencies and universities involved. From the perspective of total federal participation in salmon ranching research on technology, it seems unlikely that answers are readily available for questions listed in the "Statement of Work," viz.,

1) How well the technology in use meets research needs.

2) How well programs provide managers with needed data.

3) How future needs are considered and planned for.

4) How improved technology is developed and introduced.

5) How costs are justified and managed.

6) How options for improved technology, management, coordination, or reduced costs are considered.

7) Who is in charge of matching technology to needs.

8) How well the programs match legislative goals.

Undoubtedly, the individual agencies can provide answers to these and other pertinent questions in terms of internal coordination, but there is no evident overall coordination among agencies and universities receiving federal funds to insure effective planning and coordination of the total federal commitment. The problem is complex and deserves further attention.

The federal government has an obligation and responsibility to manage offshore salmon fisheries in order to protect natural stocks and to insure escapements to Indian fisheries which are adequate to satisfy requirements stipulated by federal courts. Salmon ranching raises questions vital to conservation of natural populations, especially where naturally and artificially propagated fish intermingle in a common property fishery. Hatchery fish can withstand a much higher rate of exploitation than wild fish. If fishery managers permit common property fisheries to harvest ranched fish which are surplus to the needs of reproduction, intermingled natural populations will be overfished.

NMFS provides direct support to the Pacific Fishery Management Council and the North Pacific Fishery Management Council in the development and implementation of salmon fishery management plans. NMFS research staff are members of scientific and statistical committees and management plan development teams.

Pacific Marine Fisheries Commission has provided much of the coordination of research information used in the development of salmon managment plans. Research data originates largely from the PMFC member states and NMFS. PMFC enjoys a record of effective coordination of assembling and reporting research information for management purposes. However, the planning and implementation of research for management of salmon fisheries is largely the responsibility of the individual states. Federal funds are commonly used in support of research; but the responsibility of NMFS in coordinating the planning of research does not appear to be clearly defined. The Fishery Management Councils also provide contract funds for research studies, further complicating planning and coordination and making effective management of federal expenditures more difficult.

The number of juvenile salmon released from ranching facilities into the North Pacific Ocean is predicted to increase from about three billion in 1980 to about six billion by 1990. Although such an increase can be expected to add only about 15 percent to the total biomass of salmon in the North Pacific (well below historic levels), there may be localized impacts from overstocking. Puget Sound and certain estuaries with heavy concentrations of salmon ranching facilities would most likely be among the first to be affected by possible overstocking.

There is a growing need, therefore, to coordinate marine ecosystem studies by NMFS laboratories and Sea Grant universities. Requirements for studies of ecological interactions and oceanic surveys involving salmon need to be determined.

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FISHERY MANAGEMENT AND THE MISSING INGREDIENT

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Introduction

The United States fishing industry is trying to analyze its position in relation to the past, present, and future as we march towards oblivion. Why are we witnessing this chaotic state of foreign control of our companies and markets, of major companies going bankrupt, of high retail prices preventing growth in sales, of fishermen losing their vessels because they are unable to make mortgage payments, of huge surplus inventories in certain products, and on and on? This state of affairs is even more fantastic when, at the same time, we have moved from being the sixth place fishing nation of the world, landing perhaps 5% of the world's commercial catch, to a point at which we now own, through management control, 25% or more of this catch.

A major cause that must be faced is that the large team of scientists and economists controlling the management of our future have "benched" one of the key players, the engineer and technologist who must handle, process, package, and distribute the end products. We can do a wonderful job of legislating against environmental impacts, of determining the biomass in the oceans and of allocating catches while dreaming of the future. However, without the practical link of getting the product to a protein-hungry consuming world so that the total system will be economically viable, we are living in a dream. Today, that huge biomass known as the 200-mile limit resource is contributing the same input to U.S. fishery as the practically unlimited resource of oil shale deposits in the Rocky Mountains is contributing to our present usable energy.

We complacently complain about not being able to compete with foreign governments who are supplying some 60% of the fish consumed in the United States, much of it from waters within our own Fisheries Conservation Zone. Why is this possible? Because these foreign companies understand the economics of harvesting and selling natural resources. We are calculating the economics of harvesting, processing, and marketing huge volumes of bottomfish or groundfish based on recovering the fillet, or 25% of the raw material, while the foreign fishing fleets are amortizing their costs over 100% of that raw material. You can argue resource availability, conservation, ecology, allocations, and all of the other management factors, but until technology is applied to "total utilization" of the resource, the U.S. fishing industry is not going to be a major factor in harvesting the relatively low-priced, high-volume, off-shore fish that exist in our waters.

Before analyzing how we can exploit the 200-mile limit fish to our benefit, let us look at the changes that are taking place in the Northwest and Alaskan fisheries and the relationship between the two geographical areas.

The changing fisheries of the Northwest and Alaska

Consider some trends taking place in this area of the fishing world. Understanding these circumstances provides a basis for determining whether there is a difference between Alaska and the Northwest which will alter future activities in their respective fishery industries.

1. High cost of present products

Since shortly before the turn of the century, salmon has been the dominant seafood in the Northwest and Alaska. This much-sought-after fish has also dominated the thinking of the fishing industry, the state, federal and local bureaucracies, educational institutions, and the public. In Alaska, king crab became a major industry during the 1960s, followed by tanner crab and shrimp. Halibut, of course has been the major long-line fishery regulated by the international agreements between Canada and the U.S. Dungeness crab, oysters, clams, and relatively small volumes of bottomfish round out the list of seafood that have supported the industry in the past. It should be noted that most of these raw materials are processed into high-quality, high-priced products. In fact, the cost of many of these products has risen so high that consumer opposition is beginning to be felt by the industry. This trend is particularly noted in the U.S., a beef eating nation where many seafood products are priced well below beef.

2. Trend toward frozen products

The demand for frozen salmon, crab, shrimp, and other seafoods is growing at a much faster rate than that for canned products. This tendency has been reflected by the rapid increase in freezing operations in Alaska. Since the seasonal nature of these fisheries greatly limits the locations where permanent shore-based freezing and cold storage operations can be built and operated economically, there has been a tremendous increase in the number of floating freezer vessels operating in Alaska. Thus, the Alaskan processing industry is becoming more mobile. Furthermore, since the frozen products are in a pre-processed condition or in the final form for marketing, a greater share of the present seafood is being shipped to the Northwest for final processing and storage. This trend is particularly important to the futures of both Alaska and the Northwest and to the relationship between these two geographic areas.

3. Present fishery at its peak

Although yearly variations in catch will continue, current fishery will not substantially increase in the future. Hence, any major increase in either Alaskan or Northwest fisheries will have to come from "cheaper" bottomfish. Ironically, many of the overfished segments of the marine waters under consideration continue to be pressed by new vessels being built for specific fisheries. Many of these vessels do not have the facilities and structure which would allow them to multi-fish or to be easily converted to other fisheries.

4. Large tonnage of fish available in the 200 mile limit zone

The tonnage and total market value of bottomfish stocks within the 200 mile limit area dwarf those of the high-priced seafood now being caught in Alaska and the Northwest. However, it must be remembered that bottomfish is not a new fishery. Foreign fleets have been harvesting large amounts of fish on the high seas. The FCMA gives the U.S. management jurisdiction over the area, but we can only replace foreign fishery effort as we develop the ability to harvest and handle high seas fish.

5. Different processing requirements for 200 mile limit fish

Species of fish such as pollock and hake have keeping qualities different from those of the bottomfish which Americans are used to catching and processing. While cod, lingcod, rockfish, flounder, sole, and other commonly caught species can be iced for some time prior to filleting, the largest volume of fish available to the high seas fishery have soft flesh and other biological properties that preclude handling by present methods. For example, hake and pollock must be processed to some degree soon after being caught. The minimum satisfactory processing is heading and gutting and then freezing. The best technique involves preparation of the final products immediately after landing.

6. Need for long-term U.S. investment Capital

A major portion of the money being invested in the U.S. fisheries is coming from foreign investors. The lack of a visible, well-planned future for fisheries has deterred U.S. investors, while foreign high seas fishing nations which know the future requirements for food and which, to preserve their present fishery resources coming from our waters, are investing heavily in the U.S. fishing industry. These investments include foreign ownership of major fishing and fish processing companies, in fact control of the industry, particularly salmon.

The bases for discussing the future of Northwest and Alaskan fisheries lie within the above factors. Each must be addressed if planning for the future is to be realistic.

Guidelines for future

The realities of the changes in available resources, handling and processing required, and financial uncertainties dictate certain requirements or considerations in planning for the future.

1. Processing high-priced fish

The quality of products must be kept high if the high-priced seafood is to maintain its position, In many instances, mediocre canned products such as salmon are accepted by the consumer. However, additional texture and odor problems, prevalent in low quality frozen products, are not acceptable. Continuing growth of the market for foozen seafoods depends on maintaining high quality through better understanding of handling and preservation techniques. Yearly variations, including periodic gluts will continue to prevail in the seasonal fisheries, and poor or mediocre management cannot continue to be tolerated in production planning for freezing and transporting fish. This is particularly important when regulatory pressures are going to continue increasing.

2. Processing bottomfish

It is a delusion to talk about an expanding bottom fishery being combined with the present seasonal industry, especially that of salmon, to give added stability to each. There are few areas in Alaska handling large amounts of salmon that are suitable for large scale processing of bottom fish. Furthermore, the present, government sponsored blue sky feasibility reports on the future of 200-mile zone are severely misleading to those trying to plan for a realistic future.

Originally, bottomfish were designated as those caught by trawling operations that drag the bottom for such fish as cod, rockfish, flounder, and sole, usually destined to be processed into fillets. However convention has tended to designate all fish to be filleted as bottomfish even though some of the species are actually schooled pelagic fish. Depending on the size and species, the yield of fillets varies from below 20% to as high as 35%, with approximately 25% being a good average. However, these fish have 50% to 60% flesh on the carcass; thus one-half or less of the edible flesh is utilized for human food. The result of this procedure is that the "frame" or filleted carcass contains an amount of flesh equal to that removed as fillets. Unless the U.S. can utilize this fraction of the bottomfish catch for some form of human food, it is doubtful at this time that we can economically enter the tremendous market being filled by foreign fleets.

These fleets are using the total raw material, either by making fish meal from the waste or by removing the remaining flesh from frames for surimi blocks that are eventually processed into kamoboko (Fig. 1). Furthermore, a high percentage of the high seas catch consists of small fish that will be thrown away as too small to fillet. These fish are also being utilized by foreign fleets. As shown in Fig. 2, small fish can be deboned to give approximately 50% of the landed weight in minced flesh. The key to future sucess of the U.S. bottomfishery will be our ability to amortize the catch over total utilization of the raw material rather than 25% in the form of fillets.

One of the major considerations involving bottomfish is that the catching and shipboard handling or processing of the fish, particularly the most abundant species, pollock and hake, have considerably different requirements than those of the high-value species. The temperature of all bottom-fish must be lowered immediately after catching in order to prevent excessive quality reduction because of bacterial and enzymatic action. Furthermore, depending on the area, hake and pollock must be headed, gutted, and frozen shortly after being caught, because otherwise the flesh rapidly degrades to become unmarketable. The foreign fleets solve this problem by having large "mothership" processing vessels accompany the fishing vessels to the grounds. Catches can be transferred to the mothership soon after being caught, and then can be processed in a manner insuring high quality. If the U.S. is going to exploit the bottomfish stocks, they must choose between supporting the expensive mothership concept or altering the concept of bottom fishing by modi-

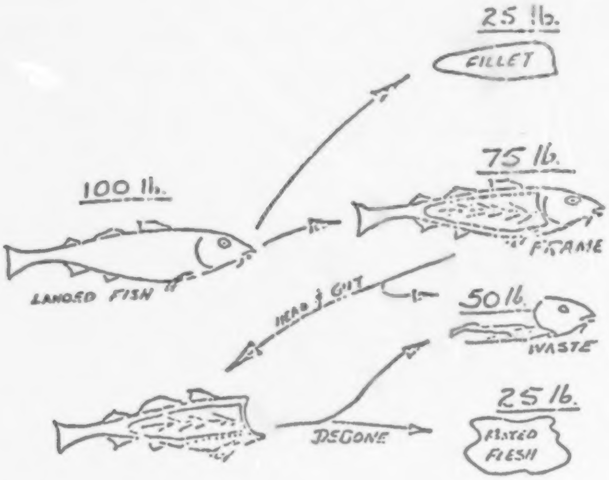
25 lb.
FILLET
75 lb.
FRAME
100 lb.
LANDED FISH
HEAD & GUT
50 lb.
WASTE
25 lb.
DEBONE
MINCED FLESH

Fig. 1 - Total Utilization of Bottomfish

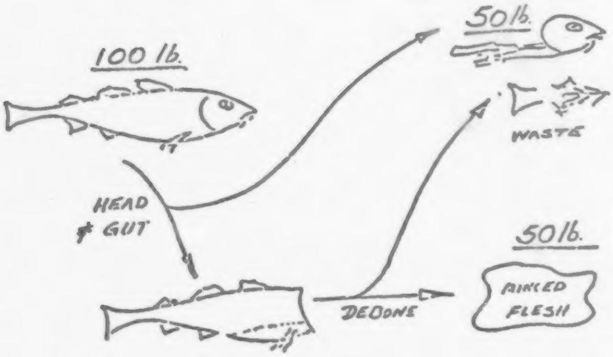
50 lb.
100 lb.
WASTE
HEAD & GUT
50 lb.
DEBONE
MINCED FLESH

Fig. 2 - Utilizing Fish Too Small to Fillet

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fying vessel design, on-board facilities, and handling procedures.

Research into methods for utilizing the large volume of deboned flesh from small fish or fillet frames is nearing the point at which large volumes of minced flesh will be in demand (Fig. 3). Although this will essentially double the marketable portion of bottomfish, the perishable nature of the flesh (made more susceptible to degradation by the cell rupturing process) imposes further alterations on the normal preparation of the fish for final processing. Minced flesh must be formulated into final products shortly after being deboned because of its short frozen shelf-life. For this reason, a large portion of the blocks frozen at sea will consist of headed and gutted fish. The fish will be thawed, filleted, and the minced flesh recovered at shore based plants that can also utilize the minced flesh for formulated products.

Shore based plants in Alaska are going to find it necessary either to prepare final formulated foods when fillets are prepared or to head and gut the bottomfish, freeze the primary product, and ship frozen blocks to the "lower 48" for subsequent secondary processing. Since minced flesh is used in the form of formulated products, usually batter-breaded and cooked, it is questionable whether these plants should install the major processing facilities necessary for handling minced fish. Hence, the immediate bottomfish products from the new processing facilities will most likely be from (1) trawling in nearshore operations and (2) frozen blocked fillets or headed-gutted fish being transhipped to secondary processors from the large catcher-processor or freezer vessels that are required for extended high seas bottom fishing.

3. Requirement for vessel support

A full study involving present owners of large fishing or processing vessels is certainly needed to complete the overview of the present Northwest and Alaskan fisheries and their relationship to the future expansion of the 200 mile limit. It is obvious that most owners have qualms about the future, feeling that there are no markets for products competing with foreign producers. However, these people must be brought into the overall planning of the major expansion of the fisheries in order to integrate some of the ideas that have been discussed.

If we accept the contention that many large vessels are required for future operations, then we must next consider the source for servicing, maintenance, and logistic support of these vessels. At the present time, the builders of larger

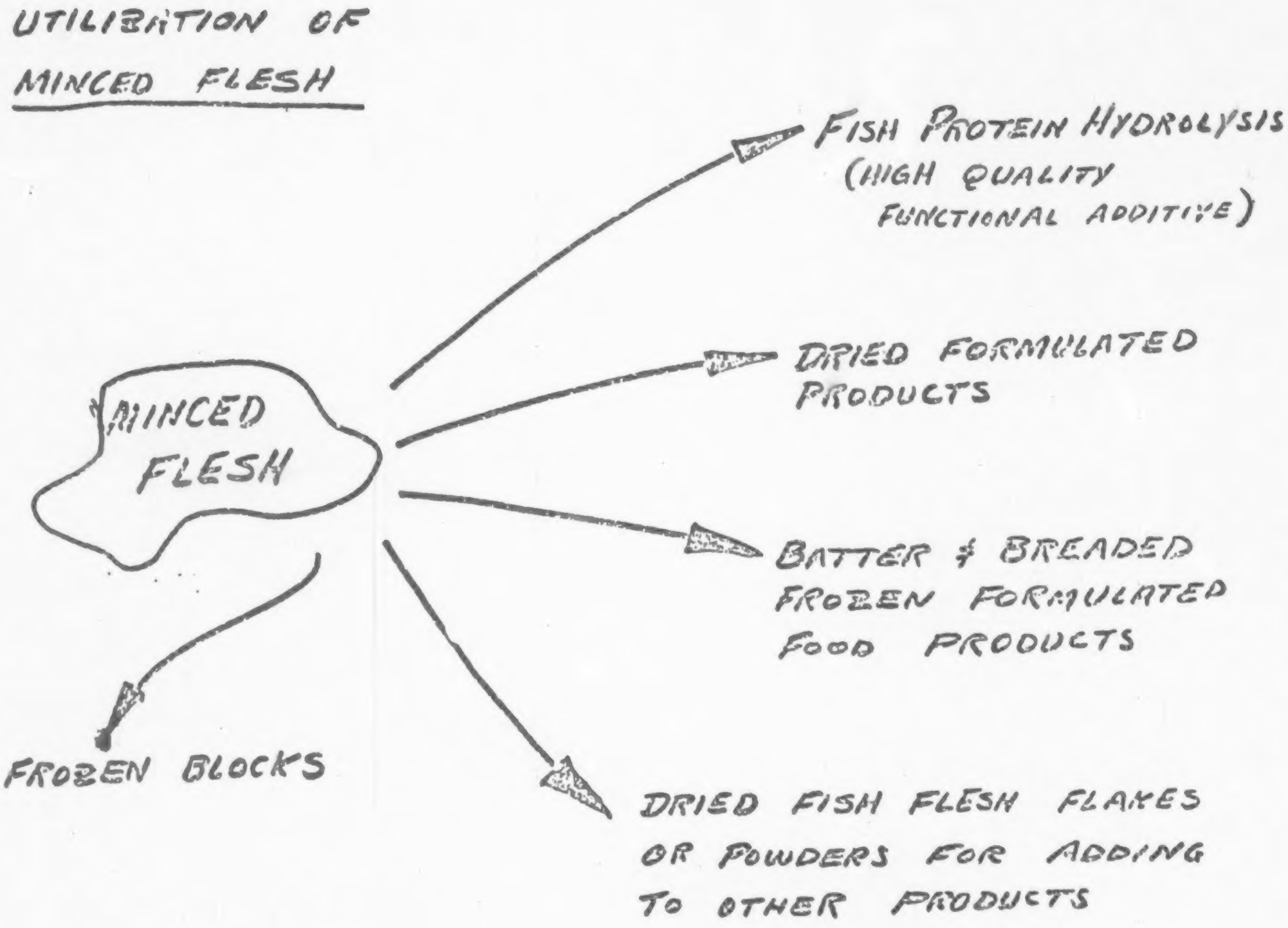
UTILIZATION OF
MINCED FLESH
MINCED
FLESH
FISH PROTEIN HYDROLYSIS
(HIGH QUALITY
FUNCTIONAL ADDITIVE)
DRIED FORMULATED
PRODUCTS
BATTER & BREADED
FROZEN FORMULATED
FOOD PRODUCTS
DRIED FISH FLESH FLAKES
OR POWDERS FOR ADDING
TO OTHER PRODUCTS
FROZEN BLOCKS

Figure 3: Utilization of Minced Flesh

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vessels for king crab catching and processing and for processing and freezing of other products are experiencing considerable problems finding support. What will happen if 200 or more vessels ranging from 125 to 350 feet in length are brought into a major fishing expansion? It is most doubtful whether private facilities will be made available for this increase of perhaps eight linear miles of vessel length. Therefore, the only foreseeable solution is for public ports to finance and build facilities in a well-planned, stepwise building program.

The servicing of vessels costing millions of dollars is going to require an entirely new approach by port managers. A fishing vessel harvesting high priced seafood and costing a few thousand to a few hundred thousand dollars can afford to participate in a seasonal fishery and then to tie up for the balance of the year. However, a vessel costing several million dollars and fishing for low cost fish must be actively engaged in fishing and/or processing all year. Hence, port facilities will have to be operated under a rigid schedule to accommodate short-term layovers for unloading products and maintaining and supplying the vessels. It is almost too late for a major study of vessel support necessary to the future fishery. Without planning and construction programs paralleling the construction and entry of large vessels into the fishery, chaos will result.

4. Development of markets

Lastly, more effort must be made to correlate "total utilization" with acceptance of new products. This effort involves integrating the available technology for producing new, wholesome products from minced flesh or cheap bottomfish with successful presentations to the consumers. Unquestionably, the entire success or failure of major 200-mile limit fishery expansion does not depend upon vessels, processing plants, distribution systems, or logistic support, but instead on the "total utilization" of the raw material. If all of the fish can be marketed in acceptable form to the consumer, the other problems, including adequate financing, will be solved by the ingenious U.S. entrepeneur and public support.

Areas needing technological development

Innovative research and development is particularly needed if full potential of the Fishery Conservation Zone is to be realized. Present and future studies must be redirected or directed in such a manner as to include vertical integration of the entire industry from harvesting and processing to distribution and marketing. Consideration of the catching, processing, and handling necessary to utilizing the entire raw material has also been inadequate. Economic operation of large vessels, better vessel support facilities, more effective processing operations, and total utilization of raw material are possible through better coordination and applied technology.

1. Shipboard operations

In planning for the high seas fishery program we must first decide what types and sizes of vessels and on-board facilities will make the U.S. competetive with foreign efforts. There are two basic methods of processing bottomfish for fillets:

a.) Fish can be filleted, packaged, and frozen directly for market. The minced flesh can then be removed after heading and gutting the filleted frame.

b.) Whole or headed and gutted fish can be frozen individually or in block form and held for subsequent filleting and minced flesh recovery.

The first method is the most practical for shore-based and large floating factories where space is not critical. The second method is the best procedure for catcher-processor vessels or factory ships that have limited processing space. Thus, it can be argued that shore-based plants should have the capacity to prepare finished products while high seas preprocessing should involve block freezing of fish for subsequent shoreside processing.

Total utilization of catch should also include the large portion of small fish that are too small for filleting. Foreign fleets debone these fish for minced flesh or reduce them to fish meal. Although no precise accuracy is claimed for the various costs, the intent of Table 1 is to show the relative economics of catching and processing 200 pounds of pollock. Considering that 100 pounds are too small to fillet, the operating profit increases startlingly as the utilization of the raw material approaches 100%.

2. Shipboard operations

A viable bottomfish industry can also be developed utilizing smaller conventional trawlers. Unexploited resources, near enough to shore in both Alaska and the Northwest, can expand the present practice of delivering iced fish. Both the high seas and the local fisheries should develop hand-in-hand as total utilization of raw material is realized. One often neglected consideration, however, is that the nearshore bottomfish are more abundant during the summer season when

Table 1: PROFIT FROM DIFFERENT UTILIZATION OF CATCH

ch	Landed Cost		Product		Operating Cost						Sales		Operating Profit		
	($/#)	($Total)	Item	Wt(lb)	Raw Mat'l		Processing		Total		$/lb	Total($)	$/lb	Total($)	$/catch
					$/lb	Total($)	$/lb	Total($)	$/lb	Total($)					
00#	.08	$8.00	Fillet	25	.32	8.00	.15	3.75	.47	11.75	.67	16.75	.20	5.00	5.00
			Waste	75											
00#	.08	$8.00	Fillet	25	.32	8.00	.15	3.75	.47	11.75	.67	16.75	.20	5.00	5.75
			Waste	75											
			Meal	15	--	---	.05	.75	.05	.75	.10	1.50	.05	.75	
200#	.04	$8.00	Fillet	25	.32	8.00	.15	3.75	.47	11.75	.67	16.75	.20	5.00	6.75
			Waste	175											
			Meal	35	--	--	.05	1.75	.05	1.75	.10	3.50	.05	1.75	
100#	.08	$8.00	Fillet	25	.16	4.00	.15	3.75	.31	7.75	.67	16.75	.36	9.00	10.00
			Minced	25	.16	4.00	.10	2.50	.26	6.50	.30	7.50	.04	1.00	
			Waste	50											
200#	.04	$8.00	Fillet	25	.20	5.00	.15	3.75	.35	8.75	.67	16.75	.32	8.00	20.00
			Waste	175											
			Surimi	75	.04	3.00	.10	7.50	.14	10.50	.30	22.50	.16	12.00	
			Meal	20	--										

the major fishing effort is for salmon. During the winter when larger vessels are required on the high seas, the smaller vessels are going to find marginal fishing.

The fact that many fish will be landed in frozen block form has major ramifications influencing the type and location of shore-based plants. Whole or headed and gutted blocks will be transported to a receiving area where they will be processed where landed or transhipped to a final destination for holding and processing.

Economic analysis may well confirm that, because of the high cost of processing in Alaska, frozen, headed and gutted fish block should be landed in U.S. Pacific Northwest ports for final processing. This procedure would be especially practical when minced flesh is recovered from the filleted frame and used for preparing formulated products. There are perhaps five to ten possible areas in Alaska where large cold storage plants with fillet and byproduct processing is feasible. However, the tremendous investment and high operating costs will probably limit many of these areas to processing near shore fresh fish and transhipping frozen products from off-shore fishing iperations. Successful utilization of small and undersized species could have a major impact on the extent of Alaskan shoreside processing facilities.

Regardless of where shoreside processing is to occur, modern plants capable of handling large volumes of block fish do not exist in the Northwest and Alaska. In fact, facilities in other parts of the U.S. can handle block fillets, but are not currently prepared to handle frozen blocks of whole or headed-gutted fish and to reclaim the flesh left after filleting.

3. Product and process development

Specific research is needed into product, processing, machinery, and facilities development for both shipboard and shore-based operations, and should include the following:

a.) Evaluation and adaptation of present methods for small fish handling (i.e. sardines) for shipboard and shore-based operations. This work must be based on the probable supply of small pollock and other small size fish available to the fishery.

b.) Integration of small fish into the general process of heading, gutting, and deboning for recovering minced flesh.

c.) Development of procedures and equipment for rapid heading and gutting of small fish.

d.) Determination of raw material and product shelf life under various conditions encountered throughout the cycle from harvesting to market.

e.) Development and evaluation of practical methods for removing skin from fresh and frozen small fish (i.e., surface freezing, burnishing, lye or enzyme peeling).

f.) Development of new products from whole, headed-gutted small fish, including pouch-packaging, canning drying, smoking and formulated products.

g.) Integration of processes for use of off-season facilities. For example, a sardine or modified sardine-type canned product could be produced in large volumes in existing salmon canneries with little facility modification.

Summary

This brief analysis of the future of the 200-mile limit fisheries for the Northwest and Alaska certainly cannot delve into the many facets that must be considered in an overall program. However, we must take some decisive action. Present and future studies must be redirected or directed in such a manner as to include vertical integration of the entire industry from harvesting and processing through to distribution and marketing. There has not been enough consideration of the catching, processing, and handling as related to utilizing the entire raw material. Such consideration is a must if we are going to compete with and replace foreign fleets in U.S. waters. Our industry has the opportunity to make a major contribution to U.S. economy and to reverse the balance of payments deficit, and at the same time to maintain control of a precious natural resource. Larger vessels, better support facilities, new processing plants, and total utilization of raw material are possible through better coordination and applied technology.

TECHNOLOGY ASSESSMENT OF HYDROACOUSTICS IN FISHERIES

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INTRODUCTION

The objective of the Ocean Research Technology Study, Fisheries Task, is to describe the existing technological systems used to conduct fisheries research and to evaluate future technology. Hydroacoustics is frequently associated with the application of technology to fisheries, and only recently has it become widely accepted as an operational fisheries management tool. In common with much technology, the hydroacoustic techniques used in fisheries today originated mainly from military developments. Existing techniques have many advantages over traditional assessment techniques, as well as some limitations. This manuscript will review the status of hydroacoustics in fisheries today with special emphasis on the present limitations, and will examine the research and development needed to minimize these limitations, especially recent technological developments which could potentially be applied. Time constraints mandate only a preliminary manuscript at this point. A more comprehensive evaluation is underway as an objective of the 1980 Sea Grant Marine Acoustics Program. An independent evaluation is also being conducted as part of the recent NOAA Workshop on Ocean Acoustic Remote Sensing.

HISTORY AND STATUS

Although hydroacoustic techniques for fishery management are relatively recent, the fact that fish could be detected with ultrasonic depth sounders was discovered over 50 years ago, and commercial fishermen have used echo sounders and sonars for fish detection for decades. The basic part of most acoustic systems used for fishery management today is still a standard depth sounder or sonar (horizontally ranging echo sounder). A quantitative understanding of the theory of hydroacoustics, i.e., the relationship between fish abundance and the intensity of echoes from fish, rather than hardware developments, has recently rendered hydroacoustics a viable management technique.

A major impetus to using modern acoustic techniques for fishery management was the development of the echo integrator and of the theoretical basis of its operation. These were first developed in Bergen, Norway in the mid '60s, and slightly later in Seattle under the Sea Grant Program at the University of Washington. Research on the characteristics of echo integrators and their application continued at both locations, leading to a commercial version of the analog echo integrator in Norway (the Simrad QM) and the digital echo integrator at Seattle (Thorne, 1973).

Although echo integration is the most commonly applied quantitative hydroacoustic technique today, several other approaches are being used or have been proposed. Hydroacoustics techniques can be conveniently classified into amplitude or frequency domains. Amplitude domain methods include echo integration, echo counting, and sonar mapping. Echo counting techniques depend on resolution of individual fish echoes, thus are limited to relatively low density situations. Sonar mapping measures abundance based on number and horizontal dimensions of epipelagic schools, and has been applied mostly to the California current region by NMFS SWFC and California Department of Fish and Game. Frequency domain techniques use either resonance or Doppler shift. In resonance, certain frequencies of echo are enhanced by resonant structures within the target, usually the swimm bladder. Since the resonance frequency depends on the size of the structure, resonance can indicate fish size. Doppler shift is an apparent change in the frequency of the echo as a result of target motion.

Although relatively new, hydroacoustics are becoming widely used in fisheries management. The two largest single species fisheries in the world, the Barents Sea capelin and the Peruvian anchoveta, are primarily managed using acoustics. In the U.S., the herring fisheries of Washington and S.E. Alaska are managed primarily with acoustics, and acoustic techniques contribute to management of several other species including Pacific hake, walleye pollock, anchovy, and Pacific salmon. Hydroacoustic techniques have also been widely applied in studies of fish behavior and distribution, especially in conjunction with environmental impact studies.

ADVANTAGES AND LIMITATIONS

The advantages of hydroacoustics over other resource assessment techniques are (1) independence from fishery catch statistics, (2) favorable time scale, (3) relatively low operational costs, (4) low variance, and (5) capability for absolute population estimation. Independence from fishery catch statistics allows application to unexploited or poorly-exploited stocks. Hydroacoustics also eliminates the long times necessary in gathering catch statistics. This decrease of time leads to the second advantage: unlike fishery catch statistics, which are obtained only after the fishery harvest, hydroacoustic techniques can be applied prior to harvest. This feature is especially important for short-lived fishes.

As a result of the high sampling power and efficiency of hydroacoustic techniques, operational costs are relatively low. Expenses for shiptime and manpower for data collection and analysis are the major operational costs. In all three categories, the costs are usually much lower than those in fishing.

The low variance of statistics gathered by means of acoustic techniques is also the result of the high sampling capability. The sampling power of acoustics is at least an order of magnitude higher than that of fishing.

The last advantage is the capacity for absolute estimation of population size, not a critical advantage, since most techniques for fishery management are based on relative indices such as CPUE. However, the capability for absolute estimate allows reasonably precise management without a historical data base, and ultimately leads to a much better understanding of production processes.

The limitations of acoustic assessment techniques are (1) poor species discrimination, (2) little or no sampling capability near bottom and surface, (3) relatively high complexity, (4) high initial investment, (5) lack of biological samples, and (6) potential bias associated with target strength uncertainties.

The division of acoustically-derived biomass estimates into various species requires auxiliary information which is usually obtained by subsampling with nets. Hydroacoustic identification of species is possible, but it depends mainly on establishing species-specific distributional patterns. As a result of the poor species discrimination, acoustics have been applied in predominately single-species environments.

Echosounding techniques are limited in their ability to survey near the surface and bottom of the water column and cannot resolve on bottom targets. The limitations near surface and bottom are a function of several parameters, especially pulse length. Boat avoidance is an additional complication for near surface fish.

A third disadvantage of hydroacoustic techniques is their relative complexity. Fishery biologists typically have difficulty with the mathematical, electronic, and physical concepts of hydroacoustics. Since acoustic techniques are comparatively recent, training in these concepts is not usually included in the education of fishery scientists. Furthermore, access to hydroacoustic calibration facilities is important since knowledge of hydroacoustic system parameters is critical for successful application.

Although operation costs are low, initial investment is relatively high, even for basic application. A minimal system for scientific quality data collection and echo integration analysis costs approximately $50,000. Equipment for other acoustic techniques is usually even more expensive.

A fourth limitation, lack of biological samples, is, in general, a minor concern since in most cases complementary direct capture techniques are conducted for species identification.

The last limitation is bias resulting from uncertainty in the target strength value. Amplitude-based techniques require target strength information to scale to absolute density. Information on fish target strengths is growing, but must be augmented through research.

POTENTIALLY APPLICABLE TECHNOLOGICAL DEVELOPMENTS

Any consideration of future research needs and technology in acoustic assessment must necessarily focus on the limitations to the present techniques. However, it is also both convenient and necessary to describe individual technological developments which might have application in fisheries research. The approach taken here is first to present these technological developments, then to discuss the most feasible solutions to the present limitations and methods of increasing the utility of hydroacoustic techniques in fisheries.

Echo Sounders

Although the heart of most hydroacoustic assessment systems is still a basic echo sounder or sonar, it is increasingly apparent that the demands of scientific quality are not met by the standard shelf item designed for commercial fisheries. These models do not have sufficient stability or linearity for scientific purposes. In recognition of this problem, Simrad of Norway has now produced two scientific quality echo sounder models, the EK series designed for oceanic research, and the EY-M, a smaller, portable system for inshore or aquatic work. Even these models do not meet all needs. Consequently NMFS NWAFC has developed its own scientific system, and a more versatile research sounder is now manufactured by Biosonics, Inc.

of Seattle. Each of these systems is a good example of the application of modern electronic technology to a specific task, quantitative fisheries research. The advantage of these models over commercial fisheries models is their greater precision. The disadvantage is cost.

One special type of echo sounder, recently developed for fisheries research, is the dual beam sounder (Ehrenberg, 1974), specifically designed for target strength measurement. The acoustic pulse is transmitted using a narrow bean transducer, and is received on the narrow as well as a wide beam transducer whose directivity is essentially unity over the range of interest (main lobe) of the narrow. By examining the ratio of the returns from a single fish target on these two transducers, the location of the target on the narrow bean directivity pattern can be determined, and the target strength extracted. The dual beam system provides the information on the location of the target in a way that is relatively simple and easy to implement and to process. Noise and interference create minor problems, but the major problem, in common with all *in situ* target strength measuring systems, is isolation of single fish echoes.

Sector Scanning Sonar

A conventional echo sounder or sonar transmits sound on a single transducer and usually receives echoes on the same transducer. The angle of the sound beam depends on the ratio of the wave length to the transducer size, and, thus, on the frequency of the sound and the transducer dimensions. For any given frequency, the larger the transducer, the smaller the beam angle. Since there is only a single transducer with a fixed beam angle, there is always a trade-off between resolution and sampling volume.

The sector scanning sonar eliminates this limitation. The sonar transducer is made up of several separate elements. Sound is transmitted simultaneously through all elements to form a large angle transmitted beam, but the individual elements are electronically scanned at a high rate (within one pulse length) so that, in effect, the receiver functions like many narrow beam transducers, thus achieving both large sampling power and high angular resolution.

The sector scanning sonar concept was developed in the 1950s. Its applicability to fisheries was first documented by Tucker and Welsby in 1964 in *Modern Fishing Gear of the World*. Considerable research on the sector scanning sonar has been conducted in Great Britain, especially at the Lowestoft and Aberdeen laboratories (Cushing and Harden Jones, 1979; Mitson, Shreever, and Hood, 1979). Several commercial models have become available (C-Tech Omni Sonars, Furuno models 75A and B, Krupp Atlas Fishing Sonar 950), and several are already in use by U.S. fishermen. However, the first U.S. scientific investigation using the sector scanning sonar was initiated only this year.

Because of its capacity for both high sampling power and resolution, the sector scanning sonar has tremendous potential in fisheries research. Its applications include acoustic survey, target strength measurement, and detailed study of fish behavior, including tracking.

Studies in Great Britain have primarily utilized the high resolution capability of the sector scanning sonar. The British Admiralty System operates at 300 kHz with an insonified sector of 30 by 7.5 degrees, with less than one degree angular resolution and as small as 2.5 cm range resolution. This high resolution capability has been used to examine fish school structure and fish behavior, especially in response to fishing gear.

The U.S. study, supported by NMFS, Northwest and Alaska Fisheries Center, is the first scientific study to investigate the advantages of the sector scanning sonar as a large sample search tool. The sonar used in this study has a 180 (horizontal) by 10 (vertical) degree insonified sector with about 10 degree angular resolution and as fine as 15 cm range resolution. The present study only uses the sonar for detection and subsamples with a "conventional" scientific echo sounder for quantitative echo integration analysis.

The potential use of a multiple channel echo integrator in conjunction with the sector scanning sonar has been explored by Ehrenberg (1979), who demonstrated that the sector scanning sonar can provide estimates with significantly smaller error than a conventional single transducer system. The tremendous volume of data is a major obstacle. Some schemes for digital signal processing have been proposed (Cook and Rushworth, 1979). Another factor which needs consideration is the effect of variation of target strength with aspect angle (Foote, 1979). However, the approach is feasible and would result in a tremendous sampling tool.

The use of the sector scanning sonar for target strength measurement has also been explored by Ehrenberg (1979b). One of the general problems in fish target strength measurement is the lack of knowledge of the location of the target in the transducer directivity pattern. The dual beam transducer (Ehrenberg, 1974) solves this problem with a two transducer array (wide and narrow with aligned axis).

The dual beam system suffers, however, from the same problem as that of the single beam transducer: the trade-off between sampling volume (the need for large sample size) and resolution (the requirement for single targets). The sector scanning sonar solves the sampling volume problem while retaining uniformity in one dimension of the directivity pattern. However, difficulties resulting from deviations of the actual transducer directivity from the theoretical ideal and variation in the other dimension still need to be resolved.

The capacity of the sector scanning sonar for detailed behavior studies is straightforward and extremely powerful. Unfortunately, this capability has yet to be used in U.S. fisheries research.

Split Beam Sonar

The split beam sonar differs from the ordinary sonar in that the transducer is divided into four quadrants. Echoes from each quadrant are independently processed. Information on the location of targets can be obtained by analysis of phase relationships among the various quadrants. The advantages of this capability are twofold. First, knowledge of the location of the target in the transducer beam allows direct measurement of target strength. Evaluation of the split beam sonar as a target strength measuring device has been conducted by Carlson and Jackson (1980) and Ehrenberg (1979). Second, since the split beam sonar allows location of a target in three dimensions, it is possible to measure target strength, position in the water column, and three-dimensional size of fish schools, as well as to track either schools or individual fish targets. This capability is not so extensively documented, but is briefly discussed in Carlson and Jackson (1980), and examples are given in Barry, Jackson, and Schultz (1978).

The major disadvantages of the split beam sonar are cost and complexity. Analysis of the quadrature information and phase relationships in order to obtain locational data is technically very complex. Data processing costs are extremely high compared to those of echo integration processing. Because of these factors, the split beam sonar is at this time strictly a military tool. Costs of data processing must abate considerably before its use is practical for routine fisheries assessment work, although it has present potential for special studies.

Doppler Shift Technology

Echo Doppler shift is an apparent change in the frequency of sound as a result of motion of the target. The classic example of Doppler is the change in pitch of a train whistle as it passes by. Doppler shift has many uses for speed measurement, including the radar used in traffic control. There are two major potential applications of Doppler shift in fisheries research. One is the measurement of fish school swimming speeds; and, since swimming speed is usually related to size, school swimming speed measurements can be used as a key to detection of year class or species. In addition, various species may have unique swimming motions which could provide a key to identification. Research in this area has been conducted by NMFS SWFC (Holliday, 1977).

The other potential application is in the determination of salmon escapements. Such information in a timely fashion is essential for allocation of harvest and escapement. Visual counting systems are labor intensive, subject to bias, and weirs may be deleterious in some cases. Acoustic echo counting systems have had only marginal success to date. Several features of Doppler fish detection make it attractive for enumeration of fish in rivers. The location of fish near boundaries is not as critical as it is with echo-envelope-based detection. In addition, Doppler-based detection has a greater capacity to distinguish between fish and debris, especially in the case of upstream migrating fish where debris and fish show Doppler shifts in opposite directions.

The major drawback with echo Doppler is that long pulse lengths are necessary to achieve the frequency resolution required for detection. These long pulse lengths result in reduced range resolution, thus requiring low densities for counting. Multiple target processing techniques in conjunction with Doppler shift might solve this problem.

Resonance Frequency Analysis

There are two potential applications of resonance frequency analysis in fisheries. The first is as a key to species identification. Resonance can be used to infer size and presence or absence of a swim bladder. Given a finite species assemblage and pre-established signatures for known sizes and species, this information can be used to infer species. The other potential application is as an indication of year class strength. This potential is especially applicable for short-lived fishes which predominate in an area. In this case the use of resonance would be similar to length-frequency analysis, but would possibly be less biased by selectivity.

High Frequency Technology

Virtually all of the echo sounders used in fisheries operate at frequencies between 10 and 200 kHz. The lower frequencies have better range; higher frequencies have better resolution. Recently, experiments have been conducted at much higher frequencies, in the megahertz range (C.V. Holliday, personal communication). While both the range and sampling power are very limited at these frequencies, the resolution is extremely good (on the order of 1/10° in angle and 2 cm in range). Such systems have the potential to count and size fish directly, and are particularly promising for distribution very near bottom.

Stationary Systems

Acoustic systems are usually deployed from a moving vessel. Application in a stationary mode results in greatly reduced sampling power. When, however, interest is focused on a particular area, i.e. an area of potential impact, considerably more detailed information can be obtained in the stationary mode. This type of system is particularly suited to remote (unattended) application, but its use has been inhibited by lack of development of automatic data collection/processing capability. Deployment of multiple, remote systems could potentially alleviate the problem of vessel time and reduce operations costs.

Other Possibilities

The examples outlined above of potentially applied technology are not necessarily inclusive. Several other possibilities exist, such as the CTFM sonar and finite amplitude beam forming techniques; but they are considered by this author to be presently impractical or unfeasible.

DISCUSSION

The systems described above are considered the most likely candidates for future technology transfer to fisheries. All have been used experimentally. All, to varying degrees, are expensive. Whether they are practical and feasible depends on how well they solve some of the present limitations to acoustic techniques.

Poor Species Discrimination

Any application of technology to the problem of species identification must take advantage of information on the biological characteristics of the various fish species. It is unlikely that any specific technique will provide a universal solution. Of the above techniques, only those in the frequency domain are specifically oriented to species identification. These are expensive, rather difficult to implement, and still require knowledge of the specific biological characteristics of the environment. The split beam and sector scanning sonars could conceivably identify species on the basis of distributional characteristics, but standard depth sounders could do the same, albeit less effectively. Again, the key is knowledge of the specific biology. The urgent general need in this area is not for better technology, but for better understanding of fish distributional behavior, especially diel and seasonal, and of other biological characteristics which might provide unique signatures, so that existing techniques could be effectively applied. It is entirely possible that many major marine fishes, excluding flatfish and near-shore fish, are distributionally assessible as single species at some optimal time period, due to spawning or other behavior. Swimming motions may also be unique and may provide a basis for identification by Doppler signature.

Boundary Resolution

The extent of the boundary resolution problem is not well understood because of lack of basic biological knowledge. While assessment of flatfishes with hydroacoustics is very unlikely, most roundfish are off bottom during some time periods, especially at night. Thus the problem interrelates with the species identification problem. Studies by the author have shown that it is technically feasible to survey very close to the bottom (Table 1) using deep-towed transducers and short pulse lengths. The high frequency technology is ideally suited for this purpose. Similarly, up-looking towed transducers have been applied and shown to be feasible. Thus technology is clearly available with relatively minor adjustments to minimize the boundary resolution problem. NMFS unfortunately still conducts assessment of roundfish with bottom trawls alone, despite very strong evidence of major bias, again indicating the very large gap between availability and use of technology.

High Complexity and Expense

The high complexity of acoustics has inhibited the use of even proven techniques, and has caused many problems prompting an earlier statement by the author (Thorn, 1978) that "historically the biggest source of error is the result of biologists applying acoustic techniques without having the slightest understanding of them." Unfortunately, technology appears to be applied to fisheries in two modes: by engineers with expensive technology which they understand, inap-

Table 1. Efficiency (%) of an acoustic system in various near bottom intervals as a function of pulse length and range to bottom for a 4 degree full angle beam.

	Pulse Length											
	0.1 msec				0.3 msec				2.0 msec			
Interval above bottom (m)	Range (m) 50	100	200	400	Range (m) 50	100	200	400	Range (m) 50	100	200	400
0-0.5	80	75	65	49	52	48	42	32	0	0	0	0
0-1.0	90	87	81	79	75	73	68	59	0	0	0	0
0-2.0	95	93	90	84	88	86	84	78	25	24	23	22
0-5.0	97	97	96	94	94	94	93	91	70	69	68	67

propriately applied because of lack of biological understanding, or by biologists with expensive toys inappropriately applied because of lack of technical understanding. Seattle and La Jolla are among very few places in the world where reasonably effective interdisciplinary communication and understanding have been achieved in fishery hydroacoustics. Understanding the interaction between the biology and the technology is very important, as are education and training of fisheries scientists and directed interdisciplinary research.

Biological Samples

One of the major misconceptions which must be overcome is that any single resource assessment technique can provide satisfactory results. All techniques have advantages and limitations and need to be applied in complement. Direct net sampling naturally complements hydroacoustics, and aids in both species identification and provision of biological samples.

Target Strength

Target strength information is very important in order to increase the accuracy of present techniques. Consequently, it is receiving, and warrants, considerable research (Anon., 1978). In situ methods appear to offer the most promise. Direct in situ techniques, in which the beam pattern effect is removed from each received single echo, are more accurate and can be applied to a wider range of populations than the indirect techniques. However, indirect techniques are much easier to implement. A recent indirect technique proposed by Peterson, Clay, and Brandt (1976) shows promise, and should be given priority in research over more complicated technologies. The dual beam is proven, and its application should be continued, but its limitations rule out its exclusive use. Split beam and sector scanning sonars are promising, but may not yet warrant development for target strength alone. However, the sector scanning sonar has many other advantages, especially since it is becoming widely used in commercial fisheries and more economical. The split beam sonar has a long way to go in this regard and may never be practical. Again with target strength, certain patterns related to the biology are emerging, and careful data collection combined with a developing data base may provide the solution to this limitation. With all in situ techniques, single target isolation is a problem which needs solution.

The cage calibration technique for echo integration scaling is widely promoted by FAO, but is based on dangerous assumptions. This technique must be evaluated carefully and applied even more carefully. Cage calibrations without accoustically calibrated systems should never be undertaken.

RECOMMENDATIONS

1. Given: Increasing cost of shiptime will greatly inhibit fisheries research efforts.

   Recommended: Accelerated research on hydroacoustic techniques with particular reference to ways of reducing shiptime and cost, i.e. use of ships of opportunity with portable systems, research on species identification to reduce need for costly, time consuming net sampling, use of smaller vessels when new sampling is not required, increased vessel efficiency by use of acoustics in conjunction with other research efforts, development and application of remote systems.
2. Given: The basic technology problem in fisheries is the gap between availability and application, which results partly from the basically conservative nature of fisheries science.

   Recommended: Administrative steps should be taken to promote technology transfer in fisheries. Such action must stress interdisciplinary communication, and interdisciplinary research should be strongly encouraged in order to counteract existing institutional barriers.
3. Given: Costly shiptime is now wasted by blind, inefficient net sampling surveys.

   Recommended: Demersal trawl sampling should only be conducted in conjunction with acoustic measurements with a system which is capable of detecting a -40dB target if over 1 m from the bottom. Efforts should be directed toward evaluation of trawling catchability coefficients by use of acoustics.
4. Given: The greatest present limitation of hydroacoustic techniques is probably poor species discrimination.

   Recommended: (1) Systematic acoustic/trawling studies to determine distributional characteristics, especially diel and seasonal, which may minimize the identification problem; (2) echo classification techniques should be applied in conjunction with the above, and (3) further research on Doppler signatures from fish swimming motions should be conducted.
5. Given: Poor resolution of targets from boundaries is a present limitation.

   Recommended: High frequency, deep towed systems should be developed and applied in conjunction with demersal trawl surveys.

6. Given: The sector scanning sonar has tremendous potential in fisheries research and is rapidly being incorporated into commercial fishing operations.
Recommended: Research using sector scanning sonars should be encouraged among fisheries scientists, both for resource assessment and fish behavior studies.

7. Given: Target strength uncertainties presently limit the accuracy of acoustic techniques.
Recommended: Target strength research should be continued, both *in situ* and laboratory studies. Target strength measurements need to be made on more fish, especially those without swim bladders. Lack of target strength information should not discourage application of acoustic techniques, since they presently provide valuable relative indices and their accuracy as absolute estimators is increasing.

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The NOAA Fleet In Support Of Fisheries Research

Robert S. Wolf[1]

I. INTRODUCTION

A. HISTORY

The U.S. Coast and Geodetic Survey was founded in 1806 and retained its individuality until made a part of the Environmental Science Services Administration in 1965. At that time the USCGS fleet was made available to users from the Weather Service, the Environmental Research Laboratories, and other segments of ESSA. When NOAA was formed the USCGS was renamed the National Ocean Survey (NOS) and became the NOAA fleet operator and manager. The NOS operated 15 ships at that time.

Twelve fisheries research ships formerly operated by DOI, Bureau of Commercial Fisheries, were phased into the NOAA fleet over a one-year interval in 1972-73. Since that time one fisheries ship (KELEZ) has been transferred to other NOAA program support; two others (GILBERT, BOWERS) have been deactivated and disposed of, while another (OREGON) is scheduled for deactivation at the end of FY 80. To offset those actions, one newly built fisheries research ship (CHAPMAN) is being added to the fleet this year and funds for two replacement vessels (BOWERS, OREGON) are currently being considered for inclusion in the FY 82 NOAA budget request. Presently there are two NOAA fleet ships supporting fisheries research in the northeast (ALBATROSS IV, DELAWARE II), one in the southeast (OREGON II), one each in the southwest (JORDAN) and Hawaii (CROMWELL), and four in the northwest and Alaska (OREGON, COBB, FREEMAN, MURRE II). The CHAPMAN will also provide support for the northwest and Alaska. (Table I).

When the NMFS support ships with their crews and funding were first integrated into the fleet, they were operated for the same average number of days each ship had accomplished during the previous years of operation. Thus, the base operating year varied from 140 DAS to 210 DAS. With the implementation of the Fisheries Conservation and Management Act of 1976, the larger fisheries support ships were funded to operate 250 DAS per year. There have been some problems in maintaining this level of operations because of the limitations in time and funding for maintenance and repairs. FCMA funding also provided for "one shot" upgrading to enable the ships to better stand the rigors of an expanded operating schedule.

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B. ORGANIZATION

The NOAA fleet is operated and managed by the National Ocean Survey (NOS) within the Office of Oceanic and Atmospheric Services. The NOS is also one of the three major users of the fleet along with NMFS and Environmental Research Laboratories (ERL). (Table II).

C. NOAA CORPS

A unique aspect of NOAA fleet operation and management is the role of the NOAA Commissioned Corps. The commissioned cadre of the old Coast Survey has evolved into the NOAA Corps of today. This is a group of some 390 commissioned officers in NOAA who operate some units of the NOAA fleet for about one-third of their careers and are placed in various shore positions for the remaining time. Because of historical evolution the National Ocean Survey, including its Office of Fleet Operations (OFO), is heavily dominated by NOAA Corps personnel.

At the present time only three of the nine fisheries research vessels are commanded by NOAA Corps officers. The remainder are operated by licensed civilian deck officers, some of whom are holdovers from pre-NOAA operation.

There is no plan and few guidelines for NOAA Corps personnel to take command of the remaining NOAA fisheries research vessels, and there have been some operational problems encountered in the few cases where relatively inexperienced commissioned officers have replaced licensed mates and masters.

D. The Fleet Allocation Council

The fleet is base funded by NOAA. Program users like NMFS are not required to transfer program funds to NOAA or to NOS when they use NOAA ship time. As might be expected, competition for ship usage is high, and only about 50 percent of NOAA's ship time needs can be met by the fleet.

The NOAA fleet Allocation Council (FAC), made up of the Associate and Assistant Administrators of NOAA and the Director of the NOAA Corps, determines the distribution of NOAA ship time to the Programs. Actually, because of historical precedent, individual ship capabilities, logistics, and other considerations, about 90 percent of the allocation process is accomplished without competition so the FAC only functions actively to determine the usage of about ten percent of fleet time.

The process for obtaining NOAA ship time begins every year on July 1, 15 months prior to the beginning of the fiscal year. In NMFS each Fisheries Center submits its ship time request to headquarters including an identification of chartering intentions. Here, the four Center submissions are formatted into a single request and forwarded to the NOS Office of Fleet Operations acting as the staff arm of the Fleet Allocation Council. Using this and the other NOAA submissions, the OFO prepares a draft NOAA Ship Allocation Plan. (Table III).

The draft ship allocation plan is coordinated back with the users where most of the apparent conflicts are ironed out. In the fall, the draft plan is turned over to the Fleet Allocation Council with 5 to 10 percent of the ship time still unprioritized between user requests. Subsequent meetings of the FAC resolve final conflicts and the approved plan is usually issued to both the fleet users and the fleet operators in March, about six months prior to the onset of the fiscal year. If it becomes necessary because of major changes, a modified allocation plan may be subsequently issued.

The allocation plan divides each ship's operating year into blocks of time allocated to the various users. Most of the fisheries research ship time is allocated entirely to NMFS. Only the MILLER FREEMAN is shared about equally with the OCSEAP Program. Detailed operating schedules are developed for the first and second halves of the year by the user and operator in concert. Significant changes to the cruise schedule can be made as required by the user for operational reasons or the operator because of personnel problems, equipment failure, etc. Each cruise is covered by a cruise plan, sailing order, and cruise results report. Changes to a cruise plan are usually made on the scene as circumstances determine.

While the system is designed to work as indicated above, NMFS and other fleet users routinely plan for the use of a vessel as though it is dedicated to their support. This is logical since most of the fisheries ships are berthed near the user laboratory and were originally designed and built with the unique capabilities to support that laboratory. Fisheries ship users have also come to realize that the capability of the fleet to support their research is relatively fixed, and to ask for much more sea time than they can expect to get, based on previous years' experience, is a waste of time. NMFS seldom requests ship time in excess of ten percent over what they are used to obtaining.

E. BUDGET

The NOAA fleet budget base for FY 80 is $46.5 million. Based on the ratio of funds estimated for fisheries ship operations to the fleet total for operations, the total funds estimated to be spent on fisheries research vessels (operations, maintenance, overhead) in the fleet is $10.3 million or 22.1 percent of the total. For this NMFS expects to obtain about 2,000 days (± 40 percent) of NOAA ship support.

Added to the NOAA fleet dollar total is an estimated $2,000.K in charter costs and another estimated $250.K for sea time of NMFS-operated vessels (up to 65'), sea time included in resource assessment contracts, and from other sources. Thus, we can estimate that over $12.5 million may be spent by NOAA for NMFS research ship support during FY 80 Adjustments to base plus requested increases would raise the fleet total for FY 81 to 53.4 million and the amount spent on fisheries research ship support to an estimated $11.7 million. (Table IV).

II. How Will Technology in Use Meet Research Needs?

The research data obtained from cruises at sea by NOAA fleet ships supplemented by charters, institutional, foreign, and other ships, combined with data taken directly from the commercial fisheries forms the scientific basis for fisheries management actions. About 87 percent (based on FY 79 usage) of all fisheries research ship time including the NOAA fleet is expended in support of the NMFS Marine Resources Monitoring, Assessment, and Prediction Program (MARMAP), while the rest is in non-management-oriented research support such as Environmental Assessment, Marine Mammals and Endangered Species, and Recreational Fisheries. (Table V).

The importance of ship support to the fisheries management effort cannot be overemphasized. It is truly critical to the process since commercial catch data alone cannot provide all of the required stock assessment information. Accordingly, the NOAA fleet fisheries vessels are critical to the total ship support needed by the MARMAP program. As the core of this support, these ships are the dedicated, familiar, better equipped platforms most depended upon by the field workers.

Resource assessment technology as represented by the research vessels is the most effective we presently possess, even though it is crude and inefficient when compared with some of the acoustic remote sensing techniques now undergoing development. Hydroacoustic surveys from ships and remote sensing of the environment from aircraft and satellites are only now beginning to be used. Even when they become operational, these techniques will still require observations from ships to provide "ground truth" data.

For the immediate future there will be a continuation of conventional gathering of resource assessment data through the use of ships. As the number of management plans requiring research data continues to increase, the size of the existing fleet and the very limited funding for new NOAA ship construction combined with the limited resources for chartering vessels and/or developing remote sensing techniques could result in some reduction of quantity and quality of data support for any single plan.

III. How Well Programs Provide Data Needs to Managers

The quantity of ship time available from the NOAA fleet and from other sources does not meet all the requirements for fisheries management data production. The NOAA Fleet Allocation Council determines annually about how much NOAA ship time will be available to programs, while ship time from other sources is controlled by the program manager within the limitations of his annual program operational funding. The best estimates indicate that ship time expended on NMFS fisheries research ranges from 50 to 70 percent of the total ship time required yearly by NMFS. Since the total amount of ship time available is dependent upon so many variables a more precise estimate is not possible.

IV. How Future Needs are Considered and Planned for

Since the NOAA fleet was formed there have been at least three major studies on its capability to support NOAA programs. The latest one, the "NOAA Fleet Mix Study," has attempted to specifically identify the core level of dedicated government-owned NOAA ships required versus the amount of supplementary ship time from other sources, primarily chartering, to support NOAA's programs. This study contains a nine-year projection of ship time needs which demonstrates that without a reasonable expectation of program growth over that period it was impossible to project the growth of ship support much beyond the current level. While the results of this study are not yet public, we can say that one recommendation was the construction of ten new or replacement NOAA fleet ships, five of which would be for fisheries research support.

The government budgeting system requires detailed program planning about two years in advance of spending. This means that there is always an intervening year for which funding is uncertain between the current year and the one being planned. Effective long-range planning for large expenditures like ship construction is very difficult under these circumstances. Multi-year fleet construction plans become obsolete when all of the goals of the first year are not met and are pushed back against the goals of succeeding years. The same is true for the programs the ships support. The funding for vessel charter support is more easily decided, since it is a part of annual program funding.

Ship time needs are of course driven by program requirements. In NMFS, program requirements are generated regionally by the four regional Fisheries Research Centers based primarily on the requirement for research data to support fisheries management decisions by Regional Fisheries Management Councils.

V. How Improved Technology is Developed and Introduced

A given NOAA ship's capability to provide adequate program support is determined in two ways:

OPERATOR

The NOAA fleet operators (NOS-OFO) have the responsibility for providing updated instrumentation to provide for point-to-point movement with as much accuracy and safety as possible. Navigation and communication instrumentation are the operator's responsibility. The operator may also provide standard scientific observational instrumentation such as CTD's, meteorology packages, thermographs, echo sounders, etc., the amount of which varies from ship to ship.

USER (NMFS)

Most instrumentation on NOAA fishery research ships and the technology development behind it stems from the research programs within the National Marine Fisheries Service. In great measure it is the responsibility of the research program scientist to bring aboard, use, maintain, and repair appropriate program instrumentation. This applies also to most non-NOAA platforms.

New technology is usually coordinated between operator and program users. Sometimes higher organizational levels are required to resolve technological disputes between ship operator and user.

The development of new tactics and instrumentation for resource assessment is generally the province of the ship user although the operator is generally kept informed and provides input when and where appropriate. This kind of interaction is usually conducted at the local level rather than nationally.

VI. How Costs are Justified and Managed

A. NOAA Fleet

The Office of (NOAA) Fleet Operations is base funded by NOAA headquarters. Budgeting initiatives are generated and staffed by OFO and submitted back through their organizational chain. Very recently NOAA has decided that budget enhancement and minimum items would be prioritized by the NOAA Fleet Allocation Council rather than successively first against other National Ocean Survey items and then against Office of Oceanic and Atmospheric items from the Weather Service, the Environmental Information Data Service, the National Environmental Satellite Service, and NOS. Thus, a situation where the fleet as a NOAA-wide support service was competing against specific but not all program areas for funding appears to have been alleviated.

Budget enhancement initiatives for special NOAA fleet rehabilitation, repair, modification, or replacement construction are the responsibility of NOS. New ship construction or special program-oriented vessel modifications are the responsibility of fleet users like NOS (same agency as fleet operator), NMFS, and ERL.

Once appropriated, fleet funds are strictly the responsibility of NOS. Ship support service is their output product responsibility. The only forum for user involvement in fleet operation is through the Fleet Allocation Council which has not functioned as a fleet operations oversight group even though it is one of their designated responsibilities under NOAA Directive.

B. CHARTERS

The costs for charter vessels are contained in NMFS field program operating budgets. The portion of operating funds spent for vessel charter is the responsibility of the field manager, usually one of the four regionally-oriented Fishery Center Directors. At the present time NMFS is expending about $2.0 million/year on vessel charters, mostly on MARMAP resource assessments.

VII. How Options for Improved Technology, Management Coordination, or Reduced Costs are Considered

The options given and how they may be applied to NMFS research ship support are, in the case of the NOAA fleet, pretty well determined by the fleet operator/manager, NOS.

- Improved technology has already been discussed.
- Management of the fleet is an NOS responsibility.
- Coordination is accomplished at the national, regional, and local levels. NMFS headquarters coordinates with the NOS Office of Fleet Operations and the NOAA Fleet Allocation Council. The NOS Atlantic and Pacific Marine Centers coordinate with the NMFS Regional Fisheries Research Centers, and in those cases where NOAA ships are actually berthed at NMFS facilities a high degree of both operational and technological cooperation takes place at [illegible] level.
- Reduced costs are everyone's concern, but the major effort in cost reduction in the NOAA fleet is exerted by its managers in NOS.

VIII. Who is in Charge of Matching Technology to Needs?

While fleet users can and do make modifications in instrumentation to support their activities, NOS must have the final voice because of the impact on the ships' operation in general. Such things as weight distribution, power availability, and logistic support can impact the users' desires to introduce new technologies. The above conditions do not eliminate changes in technology, but a researcher's desire to do certain kinds of work at sea can be affected by shipboard limitations on the part of the operator.

The matching of technology to needs must be the primary responsibility of the scientists. It is his responsibility to keep abreast of the changes in technology and where possible to apply the new technologies to his research problems. He does this, of course, with the advice and assistance of technology specialists, but for the most part these specialists are a support function, just like ships.

IX. How Well the Program Matches Legislative Mandates

Ship support in NMFS serves just a few major programs, and most of these respond to legislative mandates. As previously noted, about 87 percent of all fisheries research ship time from all sources is expended in resource assessment and resource survey technology within the MARMAP program which is almost totally dedicated to the requirements of the Fisheries Conservation and Management Act of 1976. The remainder is divided between marine mammal research as required under the Marine Mammal Protection

Act of 1972, endangered species (turtle) savings gear development in support of the Endangered Species Act of 1973, National Environmental Policy Act of 1969, the National Ocean Pollution Research and Development and Planning Act of 1978, and the Migratory Gamefish Study Act of 1959. A small amount of NMFS ship time is expended in support of recreational fisheries and aquacultural activities which are not specifically mandated.

TABLE I

SHIPS OF THE NOAA FLEET

VESSEL	HPT CLASS*	LENGTH	PRIMARY USE AND USER
OCEANOGRAPHER	I	303 FT.	Ocean Investigations - ERL
DISCOVERER	I	303 FT.	Ocean Investigations - ERL
SURVEYOR	I	292 FT.	Mapping and Charting - NOS
RESEARCHER	I	278 FT.	Ocean Investigations - ERL
FAIRWEATHER	II	231 FT.	Mapping and Charting - NOS
RANIER	II	231 FT.	Mapping and Charting - NOS
MT. MITCHELL	II	231 FT.	Mapping and Charting - NOS
MILLER FREEMAN	II	215 FT	(52%)Living Resources Surveys- NMFS
			(48%)Ocean Investigations - ERL
PEIRCE	III	163 FT.	Mapping and Charting - NOS
WHITING	III	163 FT.	Mapping and Charting - NOS
McARTHUR	III	175 FT.	Mapping and Charting - NOS
DAVIDSON	III	175 FT.	Mapping and Charting - NOS
OREGON II	III	170 FT.	Living Resources Surveys - NMFS
ALBATROSS IV	III	187 FT.	Living Resources Surveys - NMFS
TOWNSEND CROMWELL	IV	164 FT.	Living Resources Surveys - NMFS
DAVID STARR JORDAN	IV	171 FT.	Living Resources Surveys - NMFS
DELAWARE II	IV	156 FT.	Living Resources Surveys - NMFS
CHAPMAN	IV	127 FT.	Living Resources Surveys - NMFS
GEORGE B. KELEZ	IV	177 FT.	Ocean Investigations - ERL
FERREL	IV	133 FT.	Current Measurements- NOS
RUDE	V	90 FT.	Mapping and Charting - NOS
HECK	V	90 FT.	Mapping and Charting - NOS
JOHN N. COBB	V	94 FT.	Living Resources Surveys - NMFS
OREGON	V	100 FT.	Living Resources Surveys - NMFS
MURRE II	VI	86 FT.	Living Resources Surveys - NMFS

* "HPT" = Horsepower/Tonnage" or the sum of shaft horsepower and gross tonnage.

CLASS I- 5000 HPT and over

CLASS II - 3500 to 4999 HPT

CLASS III - 2000 to 3499 HPT

CLASS IV - 1000 to 1999 HPT

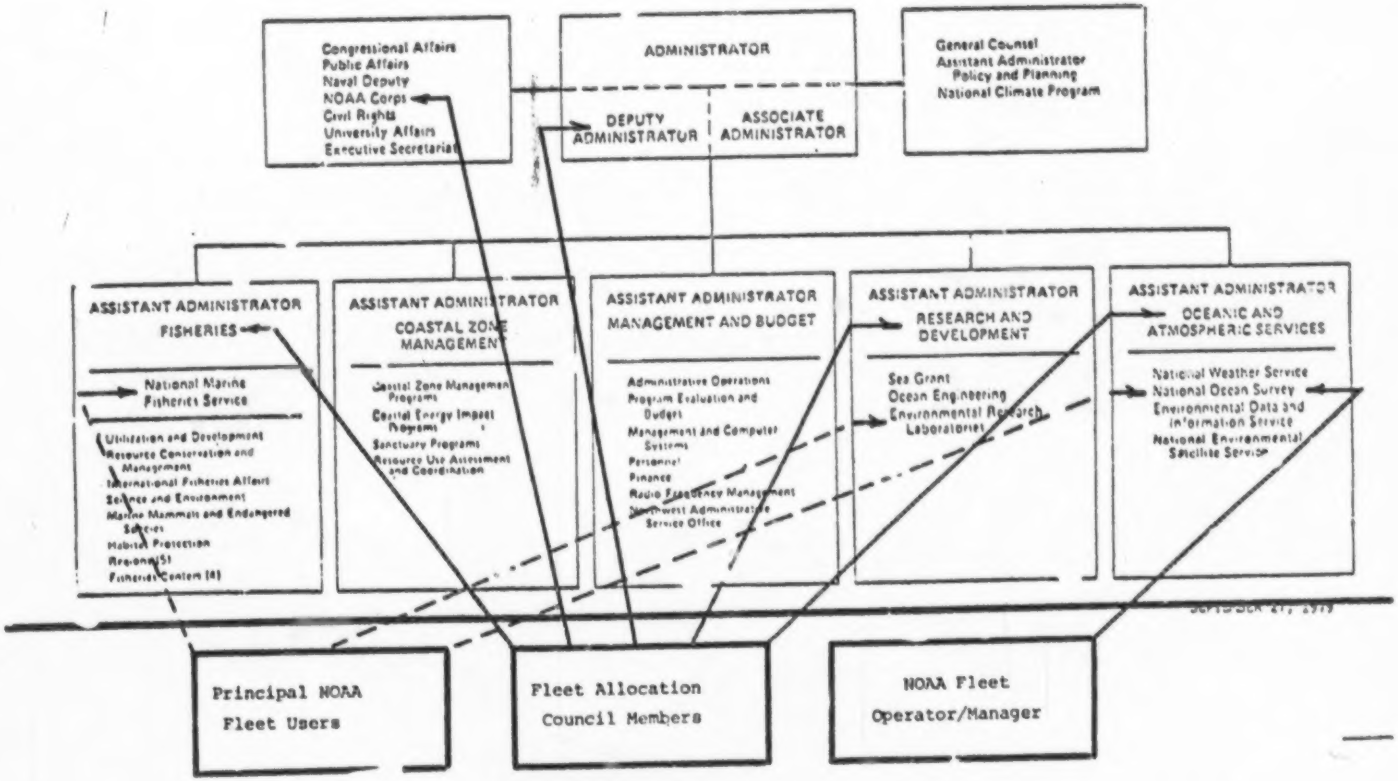
CLASS V - 500 to 999 HPT

CLASS VI - up to 499 HPT and above 65' LOA

TABLE II

NOAA FLEET FUNCTIONS RELATING TO NOAA ORGANIZATION

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration



Congressional Affairs
Public Affairs
Naval Deputy
NOAA Corps
Civil Rights
University Affairs
Executive Secretariat
ADMINISTRATOR
DEPUTY ADMINISTRATOR
ASSOCIATE ADMINISTRATOR
General Counsel
Assistant Administrator Policy and Planning
National Climate Program
ASSISTANT ADMINISTRATOR FISHERIES
National Marine Fisheries Service
Utilization and Development
Resource Conservation and Management
International Fisheries Affairs
Science and Environment
Marine Mammals and Endangered Species
Habitat Protection
Regions (5)
Fisheries Centers (4)
ASSISTANT ADMINISTRATOR COASTAL ZONE MANAGEMENT
Coastal Zone Management Programs
Coastal Energy Impact Programs
Sanctuary Programs
Resource Use Assessment and Coordination
ASSISTANT ADMINISTRATOR MANAGEMENT AND BUDGET
Administrative Operations
Program Evaluation and Budget
Management and Computer Systems
Personnel
Finance
Radio Frequency Management
Northwest Administrative Service Office
ASSISTANT ADMINISTRATOR RESEARCH AND DEVELOPMENT
Sea Grant
Ocean Engineering
Environmental Research Laboratories
ASSISTANT ADMINISTRATOR OCEANIC AND ATMOSPHERIC SERVICES
National Weather Service
National Ocean Survey
Environmental Data and Information Service
National Environmental Satellite Service
SEPTEMBER 27, 1979
Principal NOAA Fleet Users
Fleet Allocation Council Members
NOAA Fleet Operator/Manager

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TABLE III

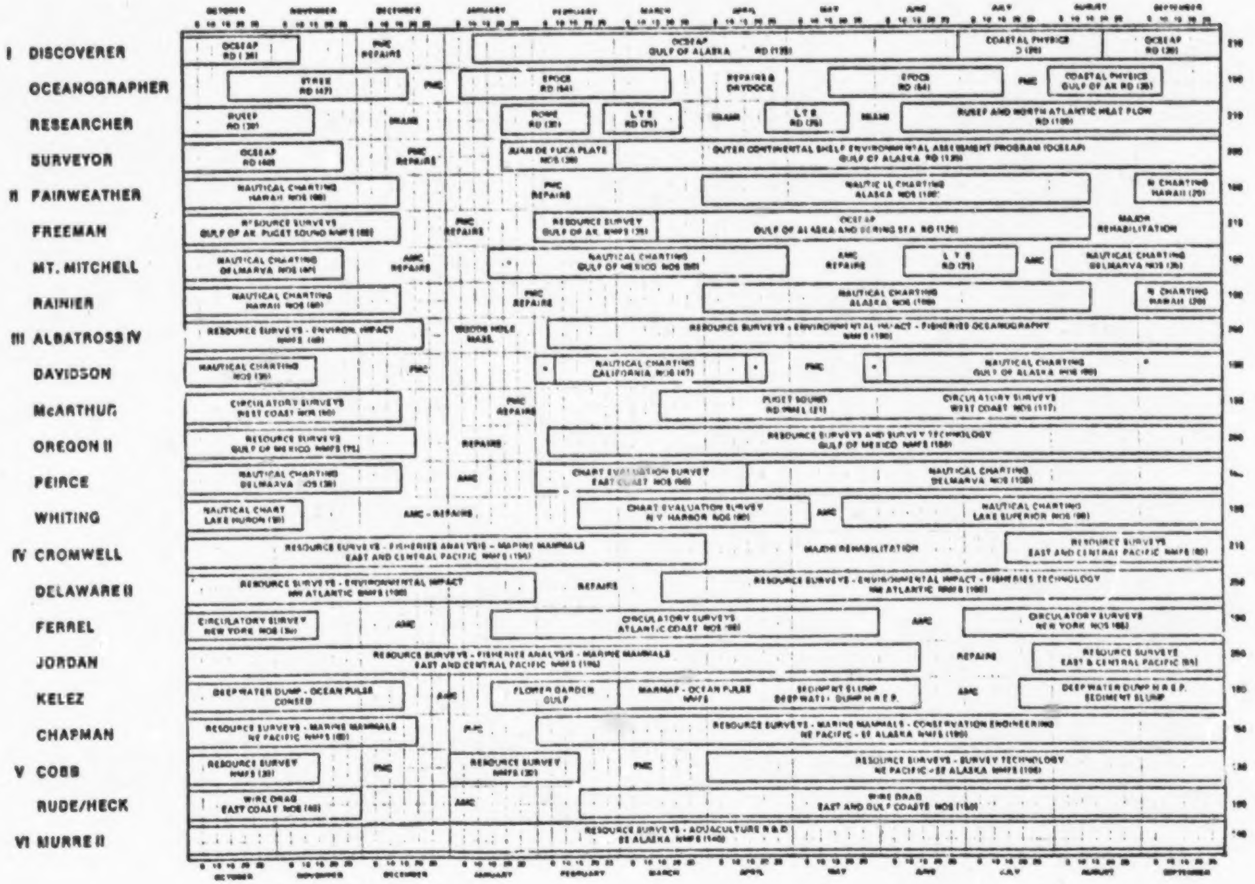
DRAFT NOAA SHIP ALLOCATION PLAN - FY81

DRAFT

FY81 NOAA SHIP ALLOCATION PLAN

Approved: ____________________ Date: ________

Chairman, NOAA FAC



* RD/PMEL ALLOCATED 21 DAYS FOR POLLUTION STUDY

TABLE IV

COST ESTIMATE FOR NOAA FLEET SUPPORT OF FCMA RELATED RESEARCH - FY 81

	Operations	%	Maintenance/ Repair	Management/ Overhead	NMFS Totals	FCMA[1] (MARMAP) Totals
NW Region (Center)						
Freeman (52%)	942.0	13.1	375.0	217.0	1,534.0	1,335.0
Chapman	893.0	12.4	355.0	205.0	1,453.0	1,264.0
Cobb	382.0	5.3	151.0	88.0	621.0	540.0
Murre II	228.0	3.2	91.0	53.0	372.0	324.0
Subtotals	2,445.0	34.0	972.0	563.0	3,980.0	3,463.0
SW Region						
Cromwell	880.0	12.2	349.0	202.0	1,431.0	1,245.0
Jordan	1,046.0	14.6	417.0	242.0	1,705.0	1,483.0
Subtotals	1,926.0	26.8	766.0	444.0	3,136.0	2,728.0
NE Region						
Albatross IV	1,088.0	15.1	432.0	250.0	1,770.0	1,540.0
Delaware II	854.0	11.9	340.0	197.0	1,391.0	1,210.0
Subtotals	1,942.0	27.0	772.0	447.0	3,161.0	2,750.0
SE Region						
Oregon II	876.0	12.2	349.0	202.0	1,427.0	1,241.0
GRAND TOTALS	7,189.0	100.0	2,859.0	1,656.0	11,704.0	10,182.0

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[1] FCMA (MARMAP) sea days amounted to 87% of all NOAA fleet support for NMFS research in FY79.

TABLE V

NMFS RESEARCH SEA DAYS SUPPORT

SOURCE	FY 79	FY 80(Projected)	FY 81(Estimated)
NOAA FLEET			
ALBATROSS IV	213	240	250
DELAWARE II	246	240	250
OREGON II	250	235	250
JORDAN	202	232	250
CROMWELL	242	250	250
FREEMAN	138	130	130
COBB	166	166	166
OREGON	196	189	-
MURRE II	145	140	140
CHAPMAN	-	100	250
KELEZ	-	30	30
OTHER	49	30	30
CHARTER VESSELS	471	700	700
FOREIGN SHIPS	400	450	450
PROGRAM BOATS	400	400	400
OTHER*	100	130	150
TOTALS	3218	3662	3696

* Donated Commercial Vessel, Research Contract, etc.

EVALUATION OF TECHNOLOGICAL SUPPORT FOR FISHERY RESEARCH BY NATIONAL MARINE FISHERIES SERVICE

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Introduction

Research for ocean technology through fishery engineering is a support activity in the National Marine Fisheries Service (NMFS) where a principal emphasis is given to fisheries research--primarily resource assessment. It is, however, recognized as an integral part of the spectrum of activities which contribute to the attainment of the higher-level research goals established by NMFS. This recognition is formally expressed in the "Fishery Engineering Policy" which was affirmed by NMFS in 1976 and reaffirmed by the Assistant Administrator for Fisheries in 1978 (NMFS Program Emphasis Document; October 6, 1978). Essentially, the policy states that NMFS will accept a positive leadership role for promoting the introduction and application of technology for attainment of national goals; promote technology only when necessary to secure these goals; and recognize fishery engineering as a logical and necessary area of investigation, similar to other major study disciplines.

Because research is a basic responsibility of the four regional research centers in NMFS, responsibility for ocean research technology also falls to the centers. Within the last decade, however, there have been a number of attempts to centralize portions or all of this technological research. For example, in 1970, the NMFS Remote Sensing Program was formally established to centralize and coordinate all remote sensing activities and then expanded in 1971 to the Fisheries Engineering Program to include all engineering related to resource assessment. A series of regional reorganizations resulted in the Fisheries Engineering Program becoming the Fisheries Engineering Laboratory, and then, as a result of a major NMFS reorganization, in 1977 it was renamed the National Fisheries Engineering

Laboratory. More recently, and as a direct result of a regional reorganization, the National Fisheries Engineering Laboratory became the National Fisheries Engineering Program within a regional laboratory, the Mississippi Laboratories of the Southeast Fisheries Center. Throughout all of these reorganizations, however, engineering research never did become centralized, since the basic responsibility for research in all areas relating to fisheries remained vested in the four research centers.

Currently, engineering research is conducted in all four research centers. There is technology transfer between the centers which is informally coordinated by the National Fisheries Engineering Program and NMFS headquarters. This coordination takes many forms, but is generally voluntary and without formal controls. An attempt to improve coordination and to evolve engineering research into a more formalized program, however, is underway (see "Program Guidelines for Fishery Engineering"; February 20, 1980).

How well the technology in use meets research needs

Any comments evaluating how well existent technology meets research needs are likely to be highly controversial because of the great diversity of technological needs among the four NMFS research centers. Furthermore, there is a general tendency among many fishery research biologists to accept an existent technology for application in their programs even though it may not adequately satisfy their needs. This is principally due to the expensive nature and long term developmental requirements of most ocean-related technology, often exceeding those of the biological or oceanographic program the technology is meant to serve. Thus, the biologist is often unwilling to commit to the need for a new technology, but focuses instead on the need for greater use of that technology which is already available.

Practically all resource assessment activities within NMFS emphasize trend analyses of populations as opposed to absolute estimates of stock abundance or biomass. For some stocks, this approach undoubtedly works well, but for others it may not be adequate to satisfy the needs of the researcher or of the manager who ultimately will use the data to manage stocks. Currently, for example, there is no means to determine the efficiency of most assessment gear used to sample stocks. Because efficiency cannot be accurately determined, researchers have tried to standardize their sampling strategies in hopes that through standardization the resulting data will be representative of changes taking place in the resource. For example, they assume that if identical nets are fished the same (speed, line scope, etc.) the resulting catches always will represent the same proportion of the sampled fish stock. Unfortunately, the validity of this assumption has never been verified; consequently, survey results can be and often are argued.

Another problem with standardization is that it is seldom complete. It varies among researchers, among research organizations, and among countries such that direct comparisons of survey data are often impossible without significant intercalibration efforts which encompass both temporal and spatial considerations. Even subtle differences such as different vessels fishing identical gears may influence the results. Thus, technological advancements which would provide for improved estimates of sampling gear efficiencies are needed, but are not vigorously sought after because of their expense, long term developmental need, and often high risk nature.

For a number of fisheries, adequate cost-effective survey technology is lacking. Examples include menhaden and other shallow water coastal pelagic species, oceanic pelagics such as billfish and tunas, most reef fish species, many crabs, and others. Because of this lack of technology, researchers are forced to depend on fishery-dependent methods of acquiring data for stock assessments and monitoring changes in the character and nature of the stocks in response to changes in fishing pressures and environmental conditions. Fishery-dependent methods for acquiring data for research applications are adequate for some fisheries, but not for those without significant pressure.

There are other areas in stock assessment research where technological advancements, while not revolutionizing assessment results, should, nevertheless, significantly improve understandings of fishery ecosystems. The remote sensing technologies, including ocean acoustics and aerospace remote sensing, offer many potentialities ranging from improvements in applications of traditional sampling techniques to synoptic monitoring of estuarine and oceanic parameters affecting the distribution, movement, recuitment, and general well-being of fish stocks. Additionally, synoptic information on ocean productivity, circulation, source and fate of pollutants, water mass patterns, and other parameters should significantly aid in monitoring the dynamics of marine ecosystems and, in turn, the ability of researchers to abstract and model fishery ecosystems.

In general, the technology available for most fishery research applications is probably no better or worse than that available to researchers in most other advanced countries. It satisfies the majority of current research needs and produces information which is useful for guiding the management and utilization of living marine resources.

How well programs provide data needs to managers

The majority of research in NMFS today is conducted specifically in response to expressed needs of resource managers and legislative mandates. For this reason, technology designed to satisfy needs of NMFS researchers will directly or indirectly satisfy most needs of management. Exceptions to this general rule fall primarily in areas relating to fisheries development, which for a number of species is technologically limited, and in the length of time it takes to make needed information available to managers. Technology to expedite the flow of information is available, but cost and personnel ceiling constraints hinder its full utilization.

A summary of selected management data needs is given in Table 1. These needs are listed according to fishery management plans, prepared in response to the Fishery Management and Conservation Act of 1976 and are subjectively assessed in high, medium, and low categories. In most instances, an assessment of "high" indicates that available data are not adequate to satisfy management needs, which in turn can be taken to mean that the technology to provide the data is either lacking or not cost effective in the context of existing budget and personnel constraints. Within the stock assessment grouping, only 9 percent of the plans show a low need for data; 25 percent show a moderate need; and 66 percent show a high need. Acquisition of life history data is generally less of a technological problem compared to stock assessment, a fact which is reflected in the data needs. Of the 56 plans, 41 percent appear to be reasonably well satisfied with life history data, 30 percent indicate a moderate need, and only 29 percent appear to be significantly deficient in this area. Although tempting, a similar assessment for the economic and sociological data needs would be unwarranted because significant research within NMFS relating to these two areas only began

TABLE 1. FISHERY MANAGEMENT PLANS REQUIRING ADDITIONAL DATA FOR EFFECTIVE LEVELS OF MANAGEMENT BY TYPE OF DATA (NEEDS EXPRESSED AS HIGH (H) - MEDIUM (M) - LOW (L)

FMP	Type of Data					
	Biological		Economic		Sociological	
	Life History	Stock Assessment	Harvesting	Processing	Harvesting	Processing
Atl. groundfish	M	H	H	H	H	H
Atl. herring	L	H	M	M	M	M
Demersal finfish	M	H	H	H	H	H
Red crab	H	H	L	L	L	L
Sea scallop	L	M	M	M	M	M
American lobster	L	M	H	H	H	H
Surf clam & Quahog	M	M	L	L	L	L
Atl. squid	H	H	L	L	L	L
Atl. mackerel	L	M	M	M	M	M
Butterfish	L	H	M	M	M	M
Other flounder	M	M	H	H	H	H
Bluefish	M	H	H	L	H	L
Tilefish	H	H	H	H	M	M
Scup	L	M	L	L	L	L
Sea bass	M	M	H	M	H	M
Dogfish	L	L	M	M	M	M
American shad	L	L	M	M	M	M
Hickory shad	L	L	M	M	M	M
River herrings	L	L	M	M	M	M
Pelagic sharks	H	H	H	L	H	L
Atl. billfishes	H	H	H	L	H	L
Calico scallops	L	M	M	M	M	M
Swordfish	M	H	H	H	H	H
Rock & Red shrimp	M	H	M	M	M	M
Stone crab	L	L	M	M	M	M
Gulf shrimp	M	M	H	H	H	H
Reef fish	M	H	H	M	H	H
Spiny lobster	L	M	H	M	H	M
Coastal pelagic	M	H	H	M	H	M
Corals	L	H	L	L	L	L
Gulf groundfish	M	H	H	H	H	H
Gulf coastal herring	H	H	M	M	M	M
Conch & whelk	H	H	M	M	M	M
Salmon	M	H	H	H	H	H
Pacific anchovy	L	H	H	M	H	M
Jack mackerel	L	H	H	M	H	M
Pink shrimp	L	M	M	M	M	M
Pacific billfish	H	H	H	L	H	L
Pacific squid	M	H	L	L	L	L
Pacific herring	M	M	M	M	M	M
Dungeness crab	L	M	L	L	L	L
Seamount groundfish	H	H	L	L	L	L
W. Pac. groundfish	H	H	M	M	M	M
Gulf of Ak groundfish	H	H	H	H	H	H
Tanner crab	L	H	M	M	M	M
Bering Sea herring	H	H	M	M	H	H
Bering Sea groundfish	H	H	H	H	H	H
King crab	L	M	M	M	M	M
Halibut	L	H	L	L	L	L
Bering Sea shrimp	L	H	M	M	M	M
Bering Sea clam	H	H	L	L	L	L
Pac. scallop	L	H	L	L	L	L
Bering Sea snail	M	H	L	L	L	L
Striped bass	M	H	H	L	H	L
Atl. tunas	H	H	H	H	H	H
Pacific tunas	H	H	H	H	H	H

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about three years ago. Thus, the data deficiencies are probably due to a lack of research rather than to inadequate or insufficient technology.

How future needs are considered and planned for

Until recently, little attention has been given to future technological needs in NMFS. This lack of attention resulted primarily from the support role of technological research and from a general failure of biological researchers to support engineering budget initiatives. Technological advancements have generally resulted from the efforts of a few individuals often forced to work with little or no base funding and direct agency support. While this at first may appear somewhat shortsighted, the biological researcher in most instances had to choose between the immediate necessity of producing assessment data using existing techniques and the gamble of allocating funds for development of new techniques without any specific guarantee of success.

This general failure to plan adequately for and to support technological research is not a recent phenomena; the failure of the Federal government to provide adequate engineering assistance to the fishing industry was recognized in 1969 by the Commission on Marine Sciences and Resources and again in 1972 by the National Advisory Committee on Oceans and Atmosphere, in their reports to the President and the Congress, as a major contributing factor to the decline of the world position of commerical fishing in the United States. Further, in 1975, the National Advisory Committee on Oceans and Atmosphere recommended to the President the formation of an institute for Engineering Research in the Ocean under the Administrator of NOAA to support work and act as a catalyst in new areas of special materials and techniques.

In response to these recommendations, among others, an Office of Ocean Engineering was established in NOAA in 1975 to exercise functional review over, and recommend policy and plans for, all of NOAA's ocean engineering and instrumentation programs; to conduct an integrated program of research, technology development, and services related to ocean engineering and undersea operations; and to serve as a national focal point for knowledge related to civil ocean engineering, a catalyst for industrial ocean development, and a mechanism for technology transfer from the military and space fields. Unfortunately, the Office of Ocean Engineering failed for several reasons to achieve its basic goals either in a planning or in a kinetic sense. Currently, NOAA is in the midst of an engineering reorganization designed to provide more focused and productive engineering research and development through improved planning, coordination, and management.

This lack of well-defined plans and statements of needs in several fisheries-related areas of ocean technology recently prompted two NOAA-wide workshops. The first was the NOAA Workshop on Oceanic Remote Sensing (August, 1979) whose objectives were to find ways of eliminating barriers to more effective use of remote sensing in all NOAA research and service areas. The second workshop, the NOAA Workshop on Ocean Acoustic Remote Sensing, was held in response to a recommendation from the first workshop to address a similar problem; but the second was limited to ocean acoustics. Both workshops identified the lack of well-defined and progressive policies in the two areas as major constraints to technological advancements and to applications for solving ocean-related research and management problems. The workshop recommendations stressed the need for better coordination and planning, offered suggestions, and in general tried to identify means to consider and plan for future needs.

Table 2 indicates the proportion of the NMFS resource assessment budget spent on survey technology development. It currently equals between two and three percent of the total, although this is probably an inflated amount. A significant portion of the funds in this category are used for purposes only marginally related to technology. A more accurate estimate would be somewhat less than two percent. This relatively poor showing compared to other research activities within the resource assessment line item, however, is not indicative of the attitudes of NMFS management, but rather of the examiners who review budget increase requests after they leave NMFS.

Table 2. Summary of NMFS Resource Assessment Budget ($K) Allocations for Survey Technology

ITEM	FISCAL YEAR		
	1979	1980	1981
Total Resource Assessment Base (Adusted)	23,000	29,000*	30,000
Net Changes in Above	+1,000	-877	-546
Survey Technology	1,300	1,300*	1,200
Net Changes in Above	-100	-100	

*Base recalculated--These are not increases to FY '79 Base

How improved technology is developed and introduced

In most instances, research for technological advancement is performed on a limited scale and with a limited funding base. A significant proportion of this research is supported by reimbursable funds, a situation not without problems since the agency contributing the funds frequently wants work accomplished which is not of very high priority within NMFS. Most of the work is not centralized since each research center retains, either in-house or immediately available in nearby universities, expertise to support its research.

The majority of engineering research in NMFS is limited to support and developmental activities as opposed to research and development for advancing technology. In this context, engineering development covers the span of engineering activities between basic research and the operational use of new equipment and systems. It includes applied research, prototype or pilot model development, and demonstration of new capabilities. Examples of such research range from development of ocean acoustic systems for fish detection, quantification, and identification; through applications of an available satellite remote sensing capability to a particular fishery-related problem; to studies of various modifications to fishing gears to reduce the incidental catch of selected species (e.g., porpoises in tuna seines).

Within the National Fisheries Engineering Program, a conscious effort has been made to involve the user in all phases of a particular developmental activity. This effort was intended to enhance ultimate introduction of the development into the user community, maximize communications in terms of requirements, and benefit from services, expertise, and facilities available from the user. Two examples serve to illustrate this approach: the LandSat Menhaden and Thread Herring Investigation and the Porpoise Containment Facility Project. The LandSat Investigation was designed to demonstrate the value of remotely sensed data for augmenting the research, management, and utilization of coastal fishery resources. Representatives from the menhaden industry were involved in all phases of the investigation, from the preparation of the initial experimental plan to submission of the final report. This involvement was accomplished in part through frequent formal meetings with the industry participants, comprehensive reviews at annual and bi-annual industry meetings, and industry contributions to the investigation of vessel, aircraft, and support personnel.

The second example differs from the first because the project was expressly designed to satisfy a research requirement of the NMFS Southwest Fisheries Center: to provide a large containment facility for noninjurious handling and processing of large numbers of porpoises at sea. Representatives from the SWFC were directly involved in planning, designing, and testing of the facility. In addition, representatives from the tuna industry periodically were involved in design reviews to ease acceptance of the facility, since it ultimately would be used from their vessels, and to gain advice and expertise in handling and deployment.

A substantial proportion of the technological research conducted in NMFS directly involves participation by other Federal agencies, NOAA groups, and state and academic organizations. The National Aeronautics and Space Administration (NASA) is probably one of the most active participants, especially in research related to remote sensing, along with NOAA/NESS, NOAA/Sea Grant, NOAA/OOE, U.S. Navy, U.S. Coast Guard, U.S. Fish and Wildlife Service, and others.

Large scale technological research and development is so expensive and demanding on personnel that there is a growing sympathy in NMFS for planning and carrying out "national programs," with one research center or another acting as "lead" or "coordinator." This is also true on a NOAA-wide and interagency scale, especially where satellite remote sensing is involved. Costs of satellite systems and data processing have gone so high that they are now generally beyond single-agency funding capabilities and must be justified and funded as multi-agency programs. This is the situation with the National Ocean Satellite System (NOSS), where NOAA, NASA, and the Department of Defense are cooperating in the development and operation of the system.

How costs are justified and managed

In NMFS, technology development costs are included and managed as a portion of the total research program. The majority of these costs are identified within the MARMAP program which consists of some 68 budget tasks included in four budget line items: Resource Surveys, Data Analysis, Survey Technology; and Fishery Oceanography. Survey technology is the principal subject of five of these tasks, but the five tasks are not exclusively devoted to survey technology any more than the remaining 63 tasks exclude all references to technology. Technological research is also performed for a number of tasks which do not fall under MARMAP, such as those relating to marine mammals and endangered species, habitat protection, fishery development, and aquaculture. A significant proportion of the technology performed for these latter tasks is coordinated by the National Fisheries Engineering Program and the Fishery Technology Coordinator in NMFS headquarters. This coordination, however, is not formal.

The proportion of the effort devoted to survey technology compared to that directed to other parts of the MARMAP budget depends essentially upon the preference of each Center Director. The responsibility of the Center Directors to provide resource assessment data does not include a requirement to fund technology research and development at any given level. Indeed, at the present time there is one research center without a specific budget task in survey technology. This center, however, is funding significant technological research within tasks relating to marine mammals.

How options for improved technology, management, coordination, or reduced costs are considered

Within the regionally oriented research programs, options for improvement in technology are the responsibility of the Center Directors. Each center submits its technology improvement initiatives annually during the budget formulation period. Some coordination generally occurs before this submission, but it is usually informal and basically for information purposes. Until recently, all technology initiatives were formally coordinated only by lumping them into a single fishery engineering or MARMAP Survey Technology initiative. For Fiscal 1982, a formal document entitled "Program Guidelines for Fishery Engineering" is being developed as an internal NMFS Program Development Plan for fishery engineering.

The establishment of a NMFS Research Council is presently being planned to assist the Assistant Administrator for Fisheries in establishing research priorities, long-range plans, and budget allocations. The Council will receive recommendations concerning technology from a proposed NMFS Engineering Advisory Panel composed of representatives from the research centers and NMFS headquarters, and chaired by the Director of the National Fisheries Engineering Program. The Panel will coordinate priority needs for fisheries research technology on a national scale in preparation for budget formulation. The Panel will also act as the first level reviewer of ongoing research technology activities at the individual centers and make appropriate recommendations for termination, continuation, or expansion to the Research Council.

Who is in charge of matching technology to needs

The research center directors are responsible for matching technology to needs in NMFS. The matching is usually accomplished through budget apportionment and prioritization after discussion with technology users and the technologists themselves. Once funding is determined, the support technology responds to the needs of the research scientists.

How well do programs match legislative mandates

No legislative mandates are directed specifically at research to support technology advancements. Indirectly, however, all legislative acts impacting research and management activities within NMFS impact programs involving fishery engineering, because the resulting technology is needed to satisfy certain legislative requirements for research and management.

REFERENCES

There are a number of relatively recent documents which directly or indirectly relate to ocean research technology in NMFS. These are listed with brief descriptive and source information.

NOAA Workshop on Oceanic Remote Sensing, Volume I: Action Summary and Report. December 1979. Contains workshop objectives and recommended actions by NOAA to support improved technological research and application experiments together with certain sensors and sensor requirements. Available from Mr. John Sherman III, NOAA/NESS, World Weather Bldg., Room 810, Washington, D.C. 20233.

NOAA Workshop on Oceanic Remote Sensing, Vollume II: Workshop Support Documentation. March 1980. Contains summaries of all presentations and discussions at the Workshop. Available from Mr. John W. Sherman III, NOAA/NESS, World Weather Bldg., Room 810, Washington, D.C. 20233.

NOAA Workshop on Ocean Remote Sensing, Volume II: Summary Report. March 1980. Contains a summary of workshop conclusions and recommendations, as well as summary reports of the discussions of four working groups on Climate and Weather, Fisheries, OCean Pollution, and Ocean Services. Available from Washington Sea Grant, Division of Marine Resources, University of Washington HG-30, Seattle, WA 98195. (Note: A Volume II from this workshop is scheduled for publication soon; it will contain programmatic and technical presentations and complete working group reports).

NMFS Fishery Engineering Policy. 1976. Contains definitions, background, relationships to NMFS goals, policy, discussion of roles, and recommendations. Available from Mr. Robert S. Wolf, NOAA/NMFS, Room 186, 3300 Whitehaven Street N.W. Washington, D.C. 20235.

NMFS Program Guidelines for Fishery Engineering (Draft). February 20, 1980. Contains definitions, discussions on engineering management and organization, a summary of generalized engineering requirements, status of NMFS engineering programs and projects, budget and schedule considerations, a copy of the NMFS Fishery Engineering Policy, and a summary of the FY 1980 National Fisheries Engineering Program. Available from Mr. Robert S. Wolf, NOAA/NMFS, Room 186, 3300 Whitehaven Street N.W., Washington, D.C. 20235.

NMFS Evaluation of the National Fisheries Engineering Laboratory. Contains summary of program activities, an evaluation of accomplishments, relative goals and objectives, references to the NAS-NAE review of NOAA research and technology, and other materials. Available from Mr. John P. Wise, NOAA/NMFS, 3300 Whitehaven Street N.W., Washington, D.C. 20235.

Organization and Management Philosophy of the National Fisheries Engineering Laboratory. 1978. Contains statements of mission and goals, organizational history, summaries of capabilities and needs, management strategy, reports and publications, project summaries, and position descriptions. Available from the National Fisheries Engineering Program, Mississippi Laboratories, National Space Technology Laboratories, NSTL Station, MS 39529.

NMFS Description and Evaluation of Stock Assessment Activities within the National Marine Fisheries Service (In preparation). Contains summaries of stock assessment methods, a discussion of research adequacy, communication of results, scientific mix, and general recommendations. Little attention is given to research technology, although it is discussed in some sections. Availability uncertain; recommend contacting Dr. Murray L. Hayes, NOAA/NMFS/Northwest and Alaska Fisheries Center, 2725 Montlake Boulevard East, Seattle, Washington 98112.

Discussion Paper on NOAA's Ocean Engineering Organization. December 1979. Contains background on recent NOAA ocean engineering policy decisions, background on various NOAA ocean engineering organizations, budget and personnel summaries, and selected organizational options. Availability uncertain;recommend contacting NOAA Office of Policy and Planning, Main Commerce Building, National Oceanic and Atmospheric Administration, Rockville, MD 20852.

OCEANOGRAPHY, ECOLOGY, AND MARINE FISHERIES

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More than ninety percent of the world catch of fin and shell fish comes from the ocean. Within the marine environment, these creatures interact continuously with other organism, both predator and prey, and with the abiotic (physical-chemical) environment. In turn, these environmental interactions, the inherent biology of the organisms, and the fishery itself determine the abundance and behavior of the harvested stocks. These observations seem to suggest that studies of relevant marine ecology would be central to fishery research. This is not, however, generally the case.

In the following discussion, distinctions are made among the acquisition of knowledge (research), monitoring (including that of stocks, stock assessment), prediction of the consequences of alternative harvesting strategies (the provision of scientific advice). Government fishery laboratories, driven by their advisory responsibilities, apply most of their efforts to the monitoring and prediction functions, while academic institutions tend to focus on research. However, as we shall see, even in universities marine ecology as it relates to fish stocks is not a vigorous field of study. The reasons for this are more institutional than scientific; among other things, there is scarcely any financial support for such efforts. These impediments will be examined after the case is made for the importance of marine ecological research to fishery management.

I start from the premise that the proper role for scientific advice in fisheries management is the prediction of the consequences of alternative harvesting strategies. The objectives of management are politically determined. Society decides what is to be optimized by the application of management controls. Important aspects of this optimization fall outside the competence of natural scientist and will not be considered in this paper. Other aspects are biological and can be interpreted by the scientist for use by the manager. The role of the scientist is not to choose among goals, but to forecast how one or another action will affect their achievement.

One reason that fishery scientists have concentrated on determining the impact of the fishery on the harvested stocks is that the fishery can be controlled.

In fact, management consists of controlling fishing effort to achieve predetermined goals. The predictions of the consequences of one or another kind, magnitude, or distribution of effort are derived from models that incorporate data on the response of individual stocks to fishing pressure together with biological parameters (e.g., growth and natural mortality). For some species in some regions, these predictions have been reasonably successful, but more often they have failed.

Common assumptions include, first, that recruitment and environmental conditions are constant and, second, that there is no significant interaction with other species. Yield per recruit may be predicted, in which case determination of recruitment (usually difficult) would prescribe yield. Neither environmental variability nor multispecies interaction can be readily incorporated in the models commonly used today.

There several reasons why this over-simplified approach is unsatisfactory. The environment varies throughout a wide range of time and space scales. In some species recruitment is highly variable; these variations are not now predictable. When heavy fishing has reduced the average life span, the inter-annual variability in recruitment can have devastating effects on the abundance of a stock. Target species interact vigorously with other species, including those of commercial interest, with the relationship changing during the animal's life. Predictions from the simple models are often too imprecise to permit rational management decisions, or are incorrect, leading on occasion to the inadvertent destruction of valuable resources.

I shall argue that an inadequate investment of funds and insufficient attention to the institutional and other non-scientific problems impeding the prosecution of marine ecological research result in increasingly inadequate scientific advice for fishery management, the cost of which to the health of our living resources and of our fisheries can be very high.

The marine ecological problem

One of the most striking developments in knowledge of the ocean in the last thirty years has been the recognition of its variability. Because of both technological and conceptual difficulties, earlier thinking about ocean focused on "average" conditions, even when observations were too scarce for meaningful averages to be determined. The major "named" currents were known, but the nature and magnitude of their changes were not. Progress was made when instruments of adequate resolution in space and time were developed and when analytical techniques of adequate power became available.

Examples of variability in the abiotic (physical-chemical) environment that may affect the abundance and behavior of fishes include the following: the surface winds drive the near-surface ocean circulation and affect vertical mixing; the distribution of wind stress is associated with horizontal divergences in the ocean surface layer that in the presence of solid boundaries (or the equator) lead to upwelling; wind stress varies in time, from the event scale of a few days through seasonal to interannual variations, and the oceanic processes driven by the wind respond with analagous variations; currents strengthen or weaken, and their trajectories, speeds, and transports change with the winds; the surface layer is thicker or thinner from place to place and time to time, and the horizontal distribution of properties is interrupted by eddies and fronts.

This physical variability couples with the biota in several ways, most directly through the productivity cycle. Variations in the vertical circulation change the availability of nutrient elements required for primary production by plants. The extent of vertical mixing determines the depth through which plant cells are distributed, and hence their access to solar energy, which in turn varies with season and latitude. The timing and intensity of these circulation and mixing events influence the kinds of phytoplankton produced, e.g., diatoms or dinoflagellates, and thus the quality as well as the quantity of food available for higher organisms. Variations in the horizontal circulation control the distributions of both the phytoplankton and their predators, concentrating them in eddies or patches or along fronts, or dispersing them in concentrations too thin for use.

Most oceanic fish are part of this planktonic system in their early life, being distributed by the same physical processes that dominate the lives of plants and invertebrates. Nearly all larvae and young fish die from starvation or predation. Recruitment success has been attributed to the coincidence in space and time of first-feeding larvae and appropriate food in sufficient concentration, the coincidence being determined by the physical processes driven by the varying wind. Just the variations physical dispersion of eggs and larvae may also determine variations in the survival of year classes. While some of the relevant processes and interactions can be identified, none of them is understood in any quantitave sense, and none is now used, other than experimentally, for predicting the success of recruitment of any species.

Another fishery problem with roots in marine ecology is that of managing the harvest of several interacting species. There is a growing move toward multispecies or "ecosystem" management that is driven by at least two considerations. First, the limits on total yield are set by basic productivity, and in regions such as the North Sea it is not possible independently and simultaneously to maximize the yields of all desired species. Second, as harvesting moves to lower trophic levels, the likelihood of depleting the food for other target species is sharply increased.

The multi-species problem is not unique to the North Sea, but studies there have illustrated the nature of the problem. For example, cod prey on herring and young haddock. If cod grow to full size before capture, that growth occurs at the expense of herring and haddock production. If herring and haddock are preferred, it might be appropriate to exterminate cod. If the interactions of these and other species were better understood, and if those engaged in their harvest could agree on their preferences, a fishing strategy could be determined that would optimize the mix of yields of desired species. A different strategy would be needed for maximum economic yield than for maximum protein yield.

As the world fish catch has levelled off at about 70 million tons per year, attention has turned to unharvested lower trophic level resources, the Antarctic krill being a conspicuous example of such resources. It has been estimated that the quantity of "surplus" krill, that which would have been eaten by the great whales at their former level of abundance, is on the order of 100 million tons per year. Even if the practical difficulties of harvesting, processing, and marketing this resource could be solved, the question arises as to the effect on the other krill-feeding creatures such as seals, penguins, and squid, and especially on the recovery rate of the now more carefully managed stocks of whales.

Agreement has tentatively been reached in on-going international negotiations on living resources of the Southern Ocean that an ecosystem approach is to be taken to their management; but neither experience in other fisheries nor quantitative knowledge of the interlocking food webs of the Antarctic waters are adequate for this approach to be applied in the near future.

Institutional and related problems

The scientific problems described above are amenable to investigation.

Indeed, they have considerable scientific interest as well as practical importance, and one might expect that considerable effort would be applied to their solution. Such efforts have been applied in some other countries, e.g. Japan, Germany, and Great Britain. Many of the important insights into the relationships among fish of different species and between them and their environment have come from the government fishery laboratories in Aberdeen and Lowestoft. But in the United States, such research is conducted in few laboratories. To understand this situation requires looking at the types of scientists and institutions involved and the means whereby such research is funded.

Most oceanographers are educated in the basic sciences, receive advanced degrees in those sciences (nearly two-thirds) or in oceanography, and conduct their research in academic laboratories. Their institutions are commonly multidisciplinary, with biologists outnumbering specialists in all other fields (physics, chemistry, geology, and geophysics). Truly interdisciplinary research is still rare. Most research proposals reflect the interests of scientists rather than the needs of funding agencies, and are most appropriately supported by the National Science Foundation and to a lesser extent by the Office of Naval Research. Oceanographic research is also done in government laboratories, e.g. of the Navy and of the National Oceanic and Atmospheric Administration, much of it closely related to mission applications.

Some fishery scientists have been educated in the basic sciences, but most come from undergraduate or graduate programs in fisheries. Fishery research is carried out primarily in government laboratories, both those of the National Marine Fisheries Service (NMFS) and of various states, and to a lesser extent in academic laboratories. In either case, the emphasis is heavily biological with few physical scientists involved. The government scientists, particularly under the pressure of implementing the Fishery Conservation and Management Act, are heavily committed to stock assessment and to the preparation of fishery management plans. While some outstanding marine ecological research is being done, e.g. at the Southwest Fisheries Center of NMFS, its general priority seems to be low.

Such research is even less common in academic fishery laboratories. In part this results from the applied education and interests of many fishery scientists, in part because research funding is not readily available. Much of the work must be done at sea, and the required resources (e.g. research vessels) are expensive.

Relevant research proposals might arise from fishery scientists, from oceanographers, or preferably from teams including both. In whatever case, such proposals are likely to seem too applied to interest the National Science Foundation and too basic to rate high priority with NMFS.

There are several unfortunate consequences of this situation. Little marine ecological research related to fisheries is being done, and little of what is being done is published in the regular scientific literature. Furthermore, few students with interest, training, and experience in such research are being graduated.

Technological constraints

The research that is required for marine ecological considerations to be used effectively for fishery predictions and management does not differ significantly in its technological requirements from other kinds of marine research. Versatile and well-equipped research vessels, devices for measuring physical and chemical characteristics of the ocean, gear for quantitative collection of biological samples, moorings and meters for measuring currents--all the paraphernalia of modern oceanography are necessary. The prosecution of this kind of research is not at present limited by the unavailability or inadequacy of these technological elements.

At some later stage, when the critical environmental factors have been identified, methods for monitoring them will be required. Cost-effective monitoring is very likely to require some new approaches. To some extent, improved earth-oriented satellites will meet this need, at least in so far as the ocean surface is involved. It should be possible to measure routinely, on a global basis and with adequate precision, parameters such as incoming solar radiation, sea surface temperature and color, surface winds and horizontal currents. It seems likely, however, that some processes that are critical to determining year class strength in some stocks will be expressed below the surface--for example, the thickness and stability of the surface layer--beyond the vision of the satellite's sensors. Subsurface sampling by research vessels will always be expensive. On shipping lanes, properly instrumented ships of opportunity may be able to do much of the work, augmented by autonomous instrumented buoys elsewhere in the ocean. Fortunately, it is probable that many of the monitoring requirements will be common to studies of climate as well as of fisheries, thus providing an additional justification for the necessary funds. Indeed, present monitoring of atmospheric variables for weather forecasting purposes already provides valuable information for fishery purposes.

It should be noted that the environmental monitoring discussed above in no way obviates the need for continued monitoring of the kind, magnitude, and distribution of fishing effort and of the stocks being exploited. The technological requirements of this sort of monitoring are discussed elsewhere, and are not dealt with in this paper. The existence of the fishery and its continual sampling of the stock greatly facilitates certain kinds of ecological studies that would be much more difficult with an unexploited, hence rarely sampled, population.

Conclusions and recommendations

Fishery management requires scientific prediction of the consequences of alternative harvesting techniques. These predictions are now commonly based on simplistic models and assumptions as well as on inadequate data. They are often too imprecise to permit rational management decisions or are incorrect, leading on occasion to the inadvertent destruction of valuable resources.

Marine ecological studies should lead to successful predictions of fluctuations in recruitment and improved understanding of the interactions among species. While some of the underlying processes have been identified and are amenable to investigation, little such research as it relates to fisheries is done in United States laboratories. The reasons for this include mismatches between fishery scientists and oceanographers, between the priorities of the institutions in which they serve, and between the sources of their research funding.

The constraints to the development of needed marine ecological research are neither scientific nor technological, but rather are almost entirely institutional. These constraints could be reduced or eliminated if actions such as the following were taken.

Short term action

1. Oceanographers and fishery scientists should initiate a discussion of the central marine ecological problems that relate to fisheries with a view to developing a strategy for research in this area. The discussion should involve both academic and government scientists and representatives of the principal potential funding sources for such research.

2. The National Marine Fisheries Service should raise the priority of its in-house marine ecological research and should also develop a long-term extramural program for such research. Academic scientists wishing to participate in this program would submit proposals for peer review and selection on their scientific merits.

3. National Science Foundation divisions concerned with supporting basic oceanographic research should ensure that marine ecological proposals that otherwise meet their scientific standards are not rejected merely because they involve fish of commercial interest.

Middle term action

1. At institutions where both fishery scientists and oceanographers are present, a continuing dialogue on scientific problems of interest to both fields should be instituted.

2. Graduate students in oceanography should be encouraged to take courses and undertake research dealing with scientific problems relating to living resources.

3. Graduate students in fisheries should be encouraged to take courses and undertake research dealing with the features and processes of the marine environment that affect the abundance and behavior of fish.

Literature note

There is no convenient comprehensive compilation of literature pertaining to the field of applied marine ecology as discussed above. Perhaps the closest approximation is the text of Cushing (1975). Cushing has been one of the major contributors to the field, and references to others of his papers can be found in the volume.

A recent study of the Ocean Sciences Board (1980) concerns many of the issues discussed in the present paper and includes a list of important references. A particularly useful paper on the multispecies problem is that of May and colleagues (1979).

Some recent symposium volumes have dealt with aspects of applied marine ecology. These include Center for Ocean Management Studies (1979), Clepper (1979), Parsons et al. (1978), and U.S. Department of Commerce (1976). Both environmental and multispecies interactions affecting North Sea stocks are discussed in

Hempel (1978).

A few scientists have been particularly productive in this field. Cushing has already been mentioned. Lasker's most recent ideas on the prediction of recruitment are summarized in an accompanying paper which includes references to others of his publications. Steele's views on the marine ecosystem were reviewed in 1974; their relation to the management of marine resources are set out in a recent paper (1979). An extensive review of the causes of variability of fish stocks will soon be published by Rothschild.

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